TECHNICAL NOTES

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TANK TESTS OF MODELS OF FLYING BOAT HULLS HAVING LONGITUDINAL STEPS

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SUMMARY

Four models with longitudinal steps on the forebody were developed by modification of a model of a conventional hull and were tested in the N.A.C.A. tank. The same afterbody, of the usual V-section, was used with all the forebodies and the depth of the transverse step at the keel was the same in all cases. Two models had two longitudinal steps on each side, one with constant dead rise and depth of steps, the other with varying dead rises between steps and different depths of steps. The other two models each had one longitudinal step and were derived from the second of the two-step models by eliminating first the inboard and then the outboard step alternatively.

The models with longitudinal steps were found to have smaller resistance at high speed and greater resistance at low speed than the parent model that had the same afterbody but a conventional V-section forebody. The models with a single longitudinal step had better performance at hump speed and as low high-speed resistance except at very light loads.

Spray strips at angles from 0° to 45° to the horizontal were fitted at the longitudinal steps and at the chine on one of the two-step models having two longitudinal steps. The resistance and the height of the spray were less with each of the spray strips than without; the most favorable angle was found to lie between 15° and 30°. Spray strips of two different widths (0.020 and 0.007 beam) were fitted and it was found that the resistance was slightly greater with the narrower strip. Eliminating the spray strip on the outboard step was found to decrease but little the effectiveness of the combination. In still another phase of the investigation the inboard- and outboard-step spray strips were shortened without adding appreciably to the resistance or the height of the bow wave.

INTRODUCTION

Longitudinally fluted or stepped bottoms have been used on the hulls of seaplanes in this country and abroad to reduce the high-speed resistance of the hull in the water and, in some cases, to reduce the height of the spray. Hulls of this type have discontinuities in the transverse sections, which may be produced either by sharp intersections of curved section lines, as in the case of the fluted bottom, or by vertical longitudinal steps in the bottom surface. Tank tests of hulls having fluted bottoms have been reported in references 1 and 2. The second type of hull, that having longitudinal steps, is considered in the present report. Both types, as used in practice, have at least one transverse step in addition to the longitudinal steps.

Although models having longitudinal steps have been tested and the results published (references 3 and 4), so far as is known no correlation of the results with the tests of similar or parent models has been made. In the present investigation, the longitudinal-step models were derived from one parent model of conventional form, and the changes in performance due to longitudinal steps of certain types were determined. Two important variables, the angle of dead rise and the depth of the transverse step, were necessarily somewhat affected by the modifications. It was believed that a comparison of the results, however, would show the general effects of converting a conventional hull into one having longitudinal steps. Further investigations in the N.A.C.A. tank of the effects of longitudinal steps are contemplated, in which it is proposed to determine the individual forces on the forebody and afterbody measured simultaneously. This type of test should permit a study of the effects on both the forebody and the afterbody due to the longitudinal steps.

Extensive tests have been made of models having spray strips installed on the chines (references 5 and 6) and it has been shown that spray strips are effective in reducing both the resistance and the spray. In the present series of tests, models with spray strips at each longitudinal step were tested to determine their effectiveness.

In the tests herein described, the effects of eliminating the spray strips on the outboard steps and of shortening the strips on both the inboard and the outboard steps

were studied to determine, if possible, the minimum number and length of strips required to keep down the resistance on a model of this type.

APPARATUS AND PROCEDURE

The N.A.C.A. tank and equipment used in these tests were essentially as described in reference 1 with the exception of a different type of towing gear, which has been described in reference 7. For this series of tests the towing gear was laterally restrained by ball-bearing rollers running on vertical guide bars fixed to the carriage.

Most of the models were tested by the general method, which consists of towing the model at several fixed trims using a number of constant loads over a range of speeds. The load on the water and the trim are made the independent test variables for which simultaneous values of speed, resistance, trimming moment, and draft are recorded. Sufficient trims are tried to determine by cross plots the best trim; that is, the trim giving minimum resistance for every load and speed used.

DESCRIPTION OF MODELS

The lines of model 11-C, the parent of the models used in the present investigation, are shown in figure 1. Conversions into longitudinal-step models were made by inserting blocks in the forebody. All the variations had the same afterbody and the depth of the step at the keel was kept constant. The following table gives the principal data required for the identification of the different models.

Model	Offsets	Photograph	Drawing	Test data	Description
	Table	Figure	Figure	Figure	
11-C	I	--	1,3(a)	4 to 9	Parent.
11-E	II	2(a)	3(b)	10 to 15	Varying dead rise[1], two longitudinal steps[2]; no spray strips.
11-E-1	--	--	--	16 to 21	11-E with three spray strips 0.020 beam in width bent down 45°; inboard and chine strips 1.78 beam, outboard 1.49 beam in length.
11-E-2	--	--	--	22 to 27	Same as 11-E-1 except spray strips bent down 30°.
11-E-3	--	--	--	28 to 32	Same as 11-E-1 except spray strips bent down 15°.
11-E-4	--	--	--	33 to 37	Same as 11-E-1 except spray strips set at 0°.
11-E-5	--	--	--	38 to 43	11-E-2 with outboard-step spray strips removed.
11-E-6	--	--	--	44 to 49	11-E with three spray strips 0.007 beam in width bent down 30°.
11-E-7	--	--	--	50 to 55	11-E-6 with outboard-step spray strips removed.
11-F	III	2(b)	3(c)	56 to 61	Constant dead rise[1], two longitudinal steps[2]; no spray strips.
11-F-1	--	--	--	62 to 67	11-F with three spray strips 0.020 beam in width bent down 30°; strip length same as for 11-E-1.
11-F-2	--	--	--	68	11-F-1 with inboard strip shortened to 1.05 beam.
11-F-3	--	--	--	68	11-F with outboard strip shortened to 0.90 beam and inboard strip shortened to 0.61 beam.
11-M	IV	2(c)	3(d)	69 to 74	11-E with inboard step eliminated.
11-N	V	2(d)	3(e)	75 to 80	11-E with outboard step eliminated.

[1] The dead rise of the individual planing bottoms separated by the longitudinal steps. (See fig.3.)

[2] Two longitudinal steps on each side of longitudinal center line of model.

RESULTS

<u>Test data</u>.- In figures 4 to 80 resistance and trimming moment are plotted against speed for each trim τ with load as a parameter. The air drag of the model was included in the water resistance of the model. The center about which the moments were taken is shown in figure 1. Moments tending to raise the bow were considered positive. Trims were measured between the horizontal and the base line, which in this case was the deck line of the model.

<u>Nondimensional results</u>.- The resistance at a given speed and load was plotted against trim to determine the minimum. The minimum values of the resistance were then reduced to nondimensional form and are presented as curves of resistance coefficient against speed coefficient with load coefficient as a parameter. The nondimensional coefficients used are defined as follows:

Load coefficient, $C_\Delta = \dfrac{\Delta}{wb^3}$

Resistance coefficient, $C_R = \dfrac{R}{wb^3}$

Trimming-moment coefficient, $C_M = \dfrac{M}{wb^4}$

Speed coefficient, $C_V = \dfrac{V}{\sqrt{gb}}$

where Δ is the load on the water, lb.

R, resistance, lb.

M, trimming moment, lb.-ft.

V, speed, ft./sec.

w, specific weight of water, lb./cu. ft. (63.5 for the present test).

b, beam of hull, ft.

g, acceleration of gravity, ft./sec.^{2}

The trimming-moment coefficient and the draft-beam ratio at rest are plotted in figures 81 and 82. They are

useful in calculating longitudinal stability and in determining water lines of the hull for various static conditions.

DISCUSSION

Effect of Longitudinal Steps

Resistance characteristics.- Longitudinal steps were found in general to increase the hump resistance and to decrease the high-speed resistance. The increase at the hump may be attributed partly to the increased turbulence produced in the cross flow by the sharp discontinuities; the decrease at high speed is due to the fact that the water is thrown clear of the bottom at the longitudinal steps and the resistance is lowered by thus decreasing the effective beam and wetted surface. When making comparisons of the models, it should be remembered that two variables, the angle of dead rise and the depth of the transverse step, are affected by variations of the longitudinal steps. The curves of resistance coefficient at best trim against speed coefficient for models 11-C, 11-E, and 11-F are shown in figures 83, 84, and 85; the load-resistance ratio at hump speed and at two high speeds is shown in figure 86. Model 11-C, the parent model, has smaller hump resistance and greater high-speed resistance than either of the two-step models, which show to the best advantage at high speeds and light loads. Model 11-E (varying angle of dead rise) has greater hump resistance and smaller high-speed resistance than model 11-F (constant angle of dead rise). Most of this change can probably be attributed to the greater depth of the inboard step of 11-E.

A comparison of the resistance of model 11-E and its derived forms, 11-M and 11-N, can be made from figures 84, 87, 88, and 89. The curves show that eliminating the outboard step of 11-E (model 11-N) lowers the resistance at the hump, probably by reducing the amount of turbulence. Resistance at high speed is not changed much because the effective beam remains the same. Eliminating the inboard step (model 11-M) considerably lowers the hump resistance but increases the resistance at high speeds and light loads since the effective beam has been increased.

It is concluded that single longitudinal-step hulls of the types tested are superior to those having two steps

inasmuch as, by the proper selection of the distance between the steps, the hump resistance can be reduced while the high-speed resistance remains relatively unaffected.

Trimming-moment and trim characteristics.- The effect on best trim produced by converting the parent, 11-C, into the two-step variations, 11-E and 11-F, is shown in figure 90. Model 11-C has, in general, a greater best trim at all speeds than the derived models, which may be partly accounted for by its greater effective angle of dead rise. Model 11-C also shows a lower maximum positive trimming moment at hump speed for best trim than 11-E and 11-F.

Effect of Spray Strips

Resistance characteristics.- A detailed comparison of the effect of angle of spray strip on resistance, made from figures 91 to 94 (C_R against C_V), shows that the resistance changes slowly with a moderate change in the angle of spray strip. The load-resistance ratio, Δ/R, plotted against the angle of the spray strip in figure 95 for three typical values of the speed coefficient was developed from these figures. At hump speed there is very little difference in Δ/R with change in angle of spray strip. At higher speeds the optimum angle apparently lies between 15° and 30°; the angle increases with load.

A comparison of the resistance coefficients at the same load and speed by means of the C_R against C_V curves of models 11-E-2 and 11-E-6 (figs. 92 and 97) shows that the resistance is not very sensitive to changes in width of spray strip. The change was purposely made great (0.020b to 0.007b) with the intention of testing intermediate widths if the results showed considerable difference. Model 11-E-2 has slightly lower resistance at speeds between the hump and moderately high speeds; at other speeds the resistances are practically the same. All the models fitted with spray strips show improvement over the model without spray strips. A comparison of the resistance curves of models 11-E-2 and 11-E-5 (figs. 92 and 96) shows that removing the spray strip from the outboard step does not greatly affect the resistance. A comparison of figures 97 and 98 gives similar results for the narrower spray strips (0.007b wide). The curves show that model 11-E-7 with two spray strips has almost as low resistance as 11-E-6 with three spray strips. Most of the loss in performance caused by removing one spray strip occurs at C_V = 4.5 to 6.0 and for C_Δ = 0.15 to 0.25.

In order to extend the investigation of the effects of spray strips to models having longitudinal steps of somewhat different form, tests were made of model 11-F fitted with three spray strips 0.020b wide set at 30° (model 11-F-1). The results (fig. 99) indicate that the addition of spray strips to 11-F gave improvement of the same order as that found for 11-E.

Additional tests were made of model 11-F equipped with three spray strips to determine whether the lengths of the strips could be reduced without seriously affecting the resistance characteristics. The curves of abbreviated test data for models 11-F-1, 11-F-2, and 11-F-3 (fig. 68) show that shortening the spray strip on the inboard step to approximately two-thirds beam length ahead of the step and shortening the strip on the outboard step to a trifle under beam length would not greatly raise the resistance. It was believed that the strips could not be further shortened without sacrificing performance inasmuch as the reduced lengths used in these tests were in the water at moderate speeds above the hump. The chine strip was not shortened because it was needed to reduce the height of the bow wave at low speeds.

Trimming-moment characteristics.- The plots of trimming moment in the curves of original data (figs. 34 to 55) show that the addition of spray strips reduces somewhat the maximum positive trimming moments at hump speed. This result bears out the results of reference 4.

Spray Characteristics

Photographs showing the spray patterns at low speeds of the models as affected by longitudinal steps and by spray strips are shown in figure 100. Observations during the tests showed that a model having longitudinal steps had more turbulence in the bow-wave formation than the parent model but a slightly reduced height of the wave. The single-longitudinal-step models showed less turbulence than those having two longitudinal steps. Adding three full-length spray strips to a two-longitudinal-step model (see fig. 100(c)) reduced the height of the wave but increased the turbulence.

Typical high-speed spray formation is shown in figure 101. The addition of spray strips 0.007b wide to model 11-F reduced the height of the spray (see fig. 101(c)); the wider spray strips (0.020b) had a slightly more pronounced effect. Shortening the length of the spray strips

on the inboard and outboard step of model 11-F, as in model 11-F-3, produced but little increase in the height of the spray.

CONCLUSIONS

The following conclusions pertain to hulls having longitudinal steps spaced one-third and two-thirds of the half beam from the keel:

1. In general, the conversion of a V-type forebody to one having longitudinal steps increases the hump resistance and decreases the high-speed resistance of the hull.

2. Reducing the number of longitudinal steps on each side from two to one decreases the hump resistance but adds somewhat to the high-speed resistance.

3. The resistance of a single-longitudinal-step model having the step at one-third the half beam is generally less than that of a model having the step at two-thirds the half beam, except for heavy loads at the hump.

4. Spray strips reduce the height of the spray at practically all speeds. Resistance is reduced at both hump and high speeds, particularly for heavy loads.

5. The optimum angle of the spray strip is between 15° and 30°. The resistance changes but little with moderate change in angle.

6. The resistance is only slightly increased with a decrease in the width of spray strip.

7. The spray strips on the outboard steps of a two-longitudinal-step model equipped with three full-length strips may be removed without sacrificing performance except at medium speeds.

8. The spray strips on the inboard steps of a two-step model may be shortened to about two-thirds beam length and the strips on the outboard steps to about one beam length without appreciably increasing the resistance.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 13, 1936.

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TABLE I

Offsets for N.A.C.A. Model No. 11-C Flying-Boat Hull (Inches)

		Distance from base line									Half breadths								
Station	Distance from F.P.	Keel	B1 [1]1.50	B2 3.00	B3 4.50	B4 6.00	B5 7.50	Main chine	Cove	Upper chine	Main chine	Cove	Upper chine	WL1 [2]12.50	WL2 11.00	WL3 9.50	WL4 8.00	WL5 6.50	Station
F.P.	0.0	4.00						4.00			0.15								F.P.
1/2	2.4	9.17	5.90					5.29			2.07						0.52	1.16	1/2
1	4.8	10.85	8.20	6.64				6.34			3.53					0.73	1.64	3.22	1
1-1/2	7.2	11.87	9.72	8.12	7.24			7.18			4.67				0.64	1.67	3.15		1-1/2
2	9.6	12.52	10.76	9.27	8.27			7.87			5.59			0.16	1.30	2.74	5.13		2
3	14.4	13.21	12.01	10.83	9.83	9.13		8.89			6.90			.93	2.76	5.10			3
4	19.2	13.47	12.62	11.72	10.91	10.18	9.62	9.56			7.71								4
5	24.0	13.58	12.94	12.23	11.53	10.85	10.22	9.97			8.17								5
6	28.8	13.66	← Elements of stations Straight lines from here aft →					10.19			8.40								6
7	33.6	13.75						10.30			8.49								7
3	38.4	13.83						10.38			8.50								8
9	43.2	13.92						10.47			8.50								9
10,F.	48.0	14.00						10.55			8.50								10,F.
10,A.	48.0	13.44						9.98			8.50								10,A.
11	52.8	12.97						9.51			8.50								11
12	57.6	12.51						9.22	8.29	8.16	8.10	8.10	8.40						12
13	62.4	12.04						9.22	7.63	7.15	6.97	6.97	8.11						13
14	67.2	11.58						9.54	7.27	6.23	5.07	5.07	7.58						14
15	72.0	11.11						10.10	7.17	5.44	2.59	2.59	6.77						15
S.P.	76.0	10.74 7.24						10.72	7.22		.20	.20							S.P.
16	76.8	7.04								4.71			5.78						16
17	81.6	5.91								4.06			4.61						17
18	86.4	4.77								3.46			3.31						18
19	91.2	3.64								2.91			1.90						19
20	96.0	2.50								2.39			.40						20

[1]Distance from center line (plane of symmetry) to buttock (section of hull surface made by a vertical plane parallel to plane of symmetry)

[2]Distance from base line to water line (section of hull surface made by a horizontal plane parallel to base line)

TABLE II

Offsets for Forebody of N.A.C.A. Model 11-E Flying-Boat Hull (Inches)

Station	Distance from F.P.	Distance from base line: Keel	Inboard step Lower	Inboard step Upper	Outboard step Lower	Outboard step Upper	Main chine	B1 1.50	B2 3.00	B3 4.50	B4 6.00	B5 7.50	Half-breadths: Inboard step	Outboard step	Main chine	WL1 12.50	WL2 11.00	WL3 9.50	WL4 8.00	WL5 6.50
F.P.	0.00	4.00					4.00								0.15					
1/2	2.40	9.17					5.29	5.90							2.07				0.52	1.16
1	4.80	10.85					6.34	8.20	6.64						3.53			0.73	1.64	3.22
1-1/2	7.20	11.87					7.18	9.72	8.12	7.24					4.67		0.64	1.67	3.15	
2	9.60	12.52					7.87	10.76	9.27	8.27					5.59	0.16	1.30	2.74	5.13	
3	14.40	13.21	11.35	11.35	9.77	9.77	8.89	12.01	10.83	9.83	9.13		2.30	4.60	6.90	.93	2.76	5.10		
4	19.20	13.47	12.20	11.89	10.53	10.48	9.56	12.74	11.66	10.85	10.11	9.60	2.57	5.14	7.71	1.96	4.21			
5	24.00	13.58	12.76	12.23	11.11	10.95	9.97		12.11	11.47	10.73	10.18	2.72	5.45	8.17					
6	28.80	13.66	13.13	12.46	11.52	11.25	10.19		12.39	11.87	11.09	10.51	2.80	5.60	8.40		6.23			
7	33.60	13.75	13.36	12.62	11.79	11.44	10.30				11.29	10.69	2.82	5.65	8.48		6.72			
8	38.40	13.83	13.49	12.73	11.94	11.55	10.38						2.83	5.66	8.50					
9	43.20	13.92	13.57	12.81	12.05	11.64	10.47						2.83	5.66	8.50					
10,F.	48.00	14.00	13.65	12.89	12.14	11.72	10.55						2.83	5.66	8.50					

TABLE III

Offsets for Forebody of N.A.C.A. Model 11-F Flying-Boat Hull (Inches)

Station	Distance from F.P.	Distance from base line: Keel	Inboard step Lower	Inboard step Upper	Outboard step Lower	Outboard step Upper	Main chine	B1 1.50	B2 3.00	B3 4.50	B4 6.00	B5 7.50	Half-breadths: Inboard step	Outboard step	Main chine	WL1 12.50	WL2 11.00	WL3 9.50	WL4 8.00	WL5 6.50
F.P.	0.00	4.00					4.00								0.15					
1/2	2.40	9.17					5.29	5.90							2.07				0.52	1.16
1	4.80	10.85					6.34	8.20	6.64						3.53			0.73	1.64	3.22
1-1/2	7.20	11.87					7.18	9.72	8.12	7.24					4.67		0.64	1.67	3.15	
2	9.60	12.52					7.87	10.76	9.27	8.27					5.59	0.16	1.30	2.74	5.13	
3	14.40	13.21	11.35	11.35	9.77	9.77	8.89	12.01	10.83	9.83	9.13		2.30	4.60	6.90	.93	2.76	5.10		
4	19.20	13.47	12.07	11.89	10.53	10.48	9.61	12.66	11.66	10.85	10.06	9.63	2.57	5.14	7.71	1.78	4.21			
5	24.00	13.58	12.53	12.23	11.11	10.95	10.11		12.11	11.47	10.71	10.22	2.72	5.45	8.17					
6	28.80	13.66	12.83	12.46	11.52	11.25	10.45		12.39	11.87	11.12	10.64	2.80	5.60	8.40		6.33			
7	33.60	13.75	13.00	12.62	11.79	11.44	10.66				11.34	10.90	2.82	5.65	8.48		7.12			
8	38.40	13.83	13.11	12.73	11.94	11.55	10.78						2.83	5.66	8.50					
9	43.20	13.92	13.20	12.81	12.05	11.64	10.88						2.83	5.66	8.50					
10,F.	48.00	14.00	13.29	12.89	12.14	11.72	10.97						2.83	5.66	8.50					

TABLE IV

Offsets for Forebody of N.A.C.A. Model 11-M Flying-Boat Hull (Inches)

Station	Distance from F.P.	Distance from base line: Keel	B1 1.50	B2 3.00	B3 4.50	B4 6.00	B5 7.50	Outboard step: Lower	Outboard step: Upper	Main chine	Half-breadths: Outboard step	Main chine	WL1 12.50	WL2 11.00	WL3 9.50	WL4 8.00	WL5 6.50
F.P.	0.00	4.00								4.00		0.15					
1/2	2.40	9.17	5.90							5.29		2.07				0.52	1.16
1	4.80	10.85	8.20	6.64						6.34		3.53			0.73	1.64	3.22
1-1/2	7.20	11.87	9.72	8.12	7.24					7.18		4.67		0.64	1.67	3.15	
2	9.60	12.52	10.76	9.27	8.27					7.87		5.59	0.16	1.30	2.74	5.13	
3	14.40	13.21	12.01	10.83	9.83	9.13		9.77	9.77	8.89	4.60	6.90	.93	2.76	5.10		
4	19.20	13.47	12.61	11.70	10.85	10.11	9.60	10.53	10.48	9.56	5.14	7.71	1.67	4.21			
5	24.00	13.58	←→	12.21	11.49	10.73	10.18	11.11	10.95	9.97	5.45	8.17	2.37				
6	28.80	13.66	←→	12.51	11.91	11.09	10.51	11.52	11.25	10.19	5.60	8.40	3.02	6.23			
7	33.60	13.75	←	→	12.17	11.29	10.69	11.79	11.44	10.30	5.65	8.48	3.59	6.72			
8	38.40	13.83	←				→	11.94	11.55	10.38	5.66	8.50	4.01				
9	43.20	13.92	←				→	12.05	11.64	10.47	5.66	8.50	4.33				
10,F.	48.00	14.00	←				→	12.14	11.72	10.55	5.66	8.50	4.59				

TABLE V

Offsets for Forebody of N.A.C.A. Model 11-N Flying-Boat Hull (Inches)

Station	Distance from F.P.	Distance from base line: Keel	B1 1.50	B2 3.00	B3 4.50	Inboard step: Lower	Inboard step: Upper	B4 6.00	B5 7.50	Main chine	Half-breadths: Inboard step	Main chine	WL1 12.50	WL2 11.00	WL3 9.50	WL4 8.00	WL5 6.50
F.P.	0.00	4.00								4.00		0.15					
1/2	2.40	9.17	5.90							5.29		2.07				0.52	1.16
1	4.80	10.85	8.20	6.64						6.34		3.53			0.73	1.64	3.22
1-1/2	7.20	11.87	9.72	8.12	7.24					7.18		4.67		0.64	1.67	3.15	
2	9.60	12.52	10.76	9.27	8.27					7.87		5.59	0.16	1.30	2.74	5.13	
3	14.40	13.21	12.01	10.83	9.83	11.35	11.35	9.13		8.89	2.30	6.90	.93	2.76	5.10		
4	19.20	13.47	12.74	11.66	10.85	12.20	11.89	10.17	9.67	9.62	2.57	7.71					
5	24.00	13.58		12.11	11.47	12.76	12.23	10.92	10.42	10.21	2.72	8.17					
6	28.80	13.66		12.39	11.87	13.13	12.46	11.40	10.92	10.65	2.80	8.40					
7	33.60	13.75				13.36	12.62	←	→	10.96	2.82	8.48					
8	38.40	13.83				13.49	12.73	←	→	11.15	2.83	8.50					
9	43.20	13.92				13.57	12.81	←	→	11.29	2.83	8.50					
10,F.	48.00	14.00				13.65	12.89	←	→	11.39	2.83	8.50					

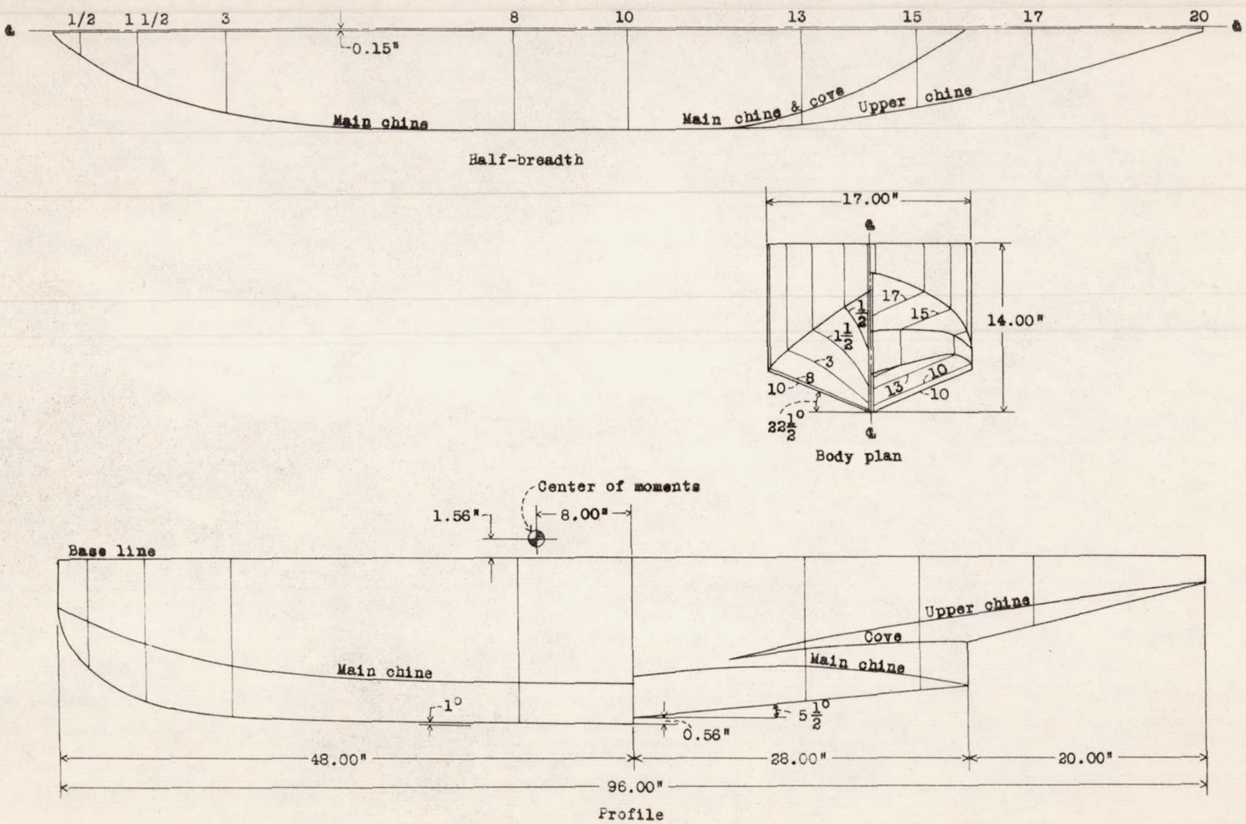
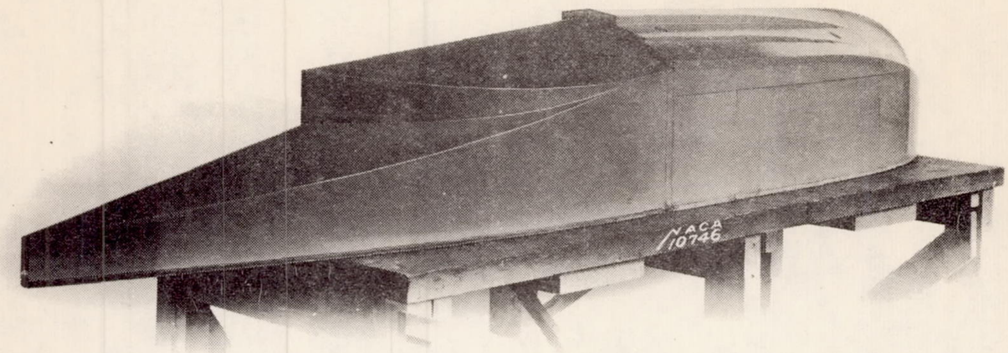
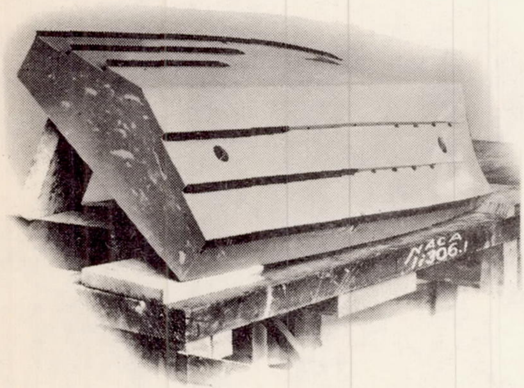


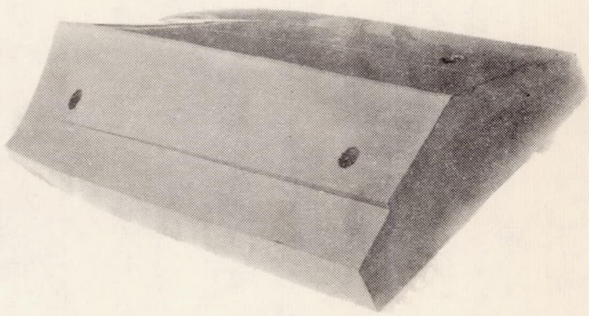
Figure 1.- Lines of N.A.C.A. model 11-C.



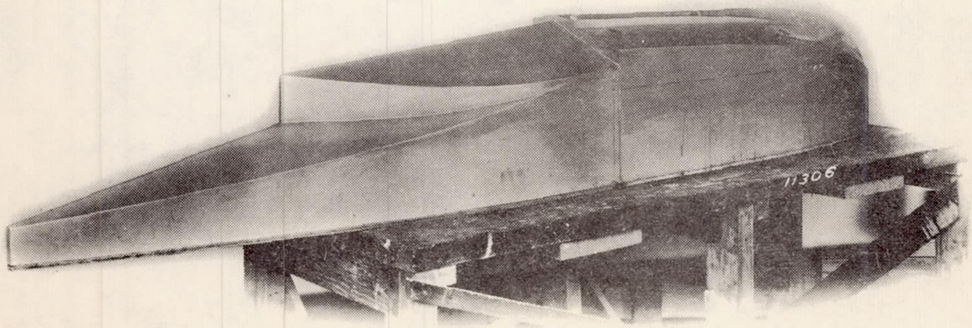
(a) Model 11-E.



(b) Block for model 11-F with spray strips.



(c) Block for model 11-M.



(d) Model 11-N.

Figure 2.- Photographs of longitudinal step models.

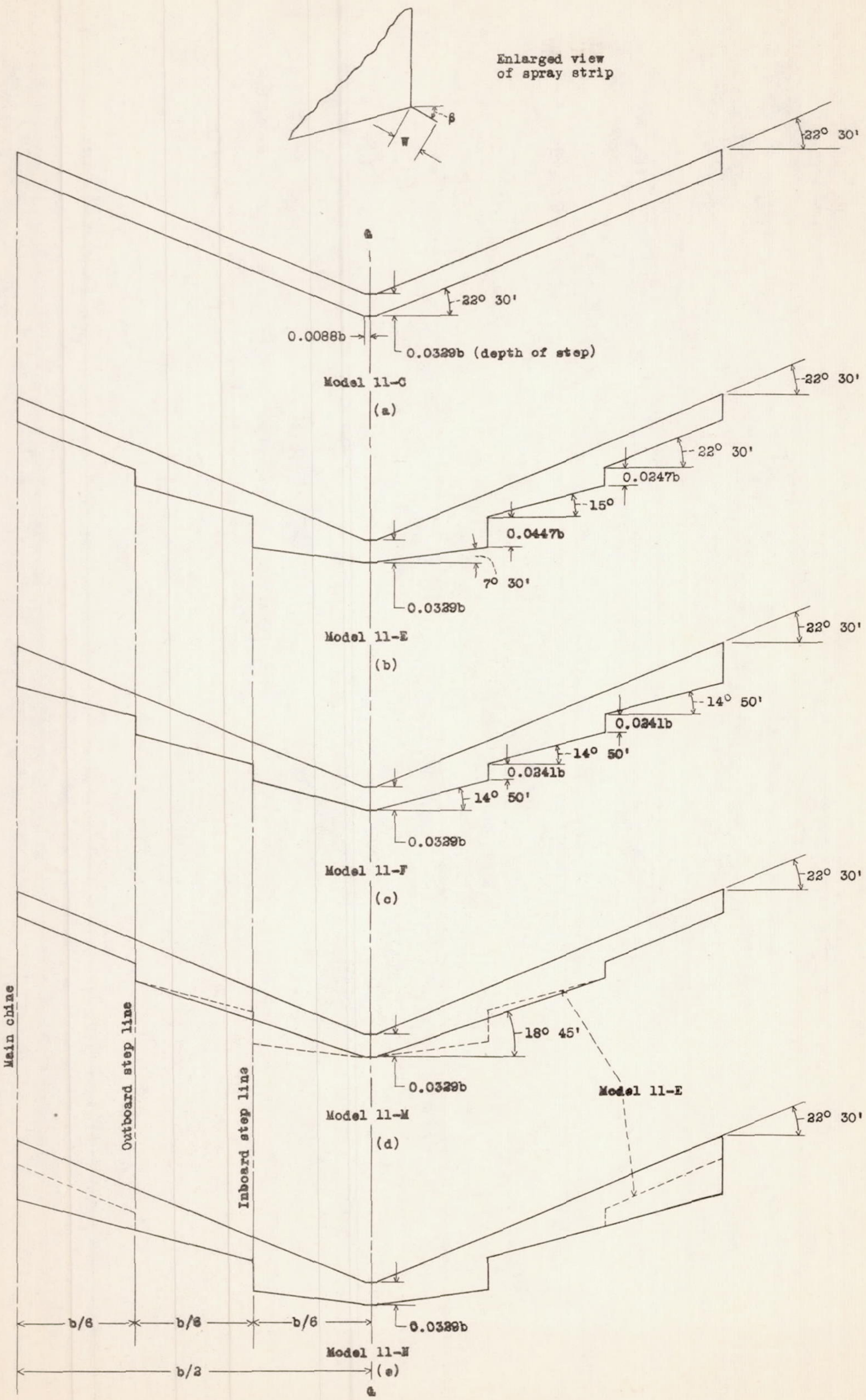


Figure 3.- Sections at transverse step (station 10)

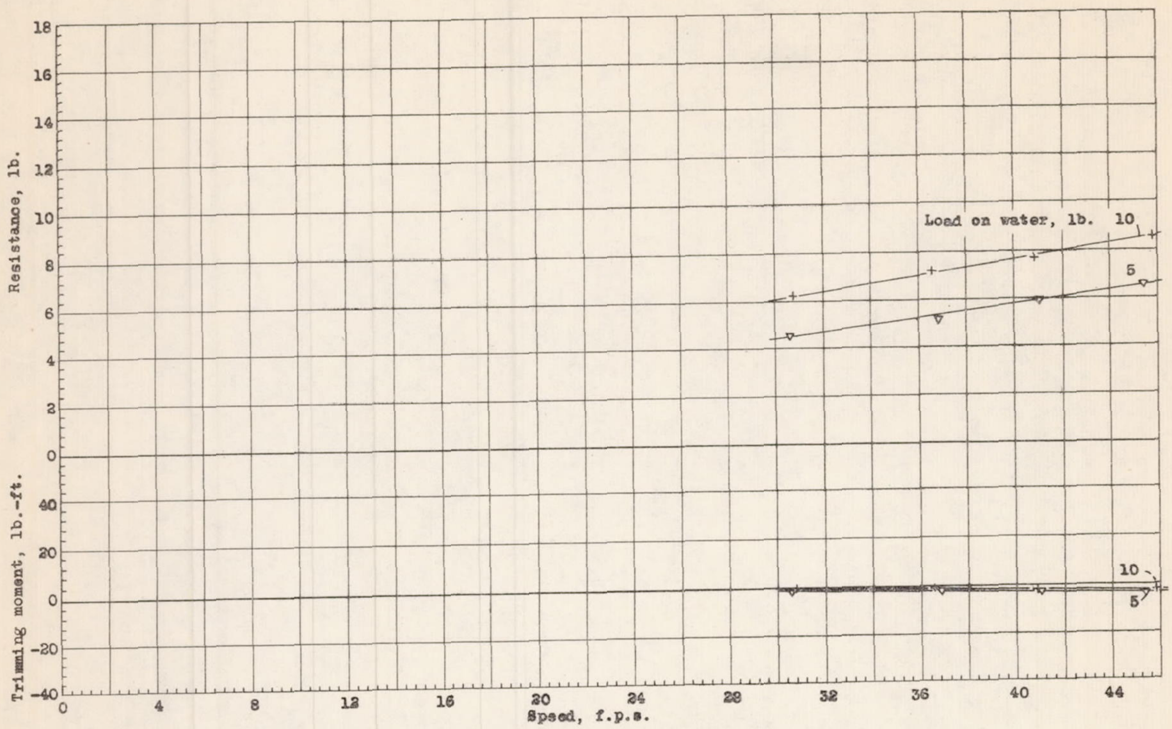


Figure 4.- Resistance and trimming moment, $\tau = 2^{\circ}$. Model 11-C.

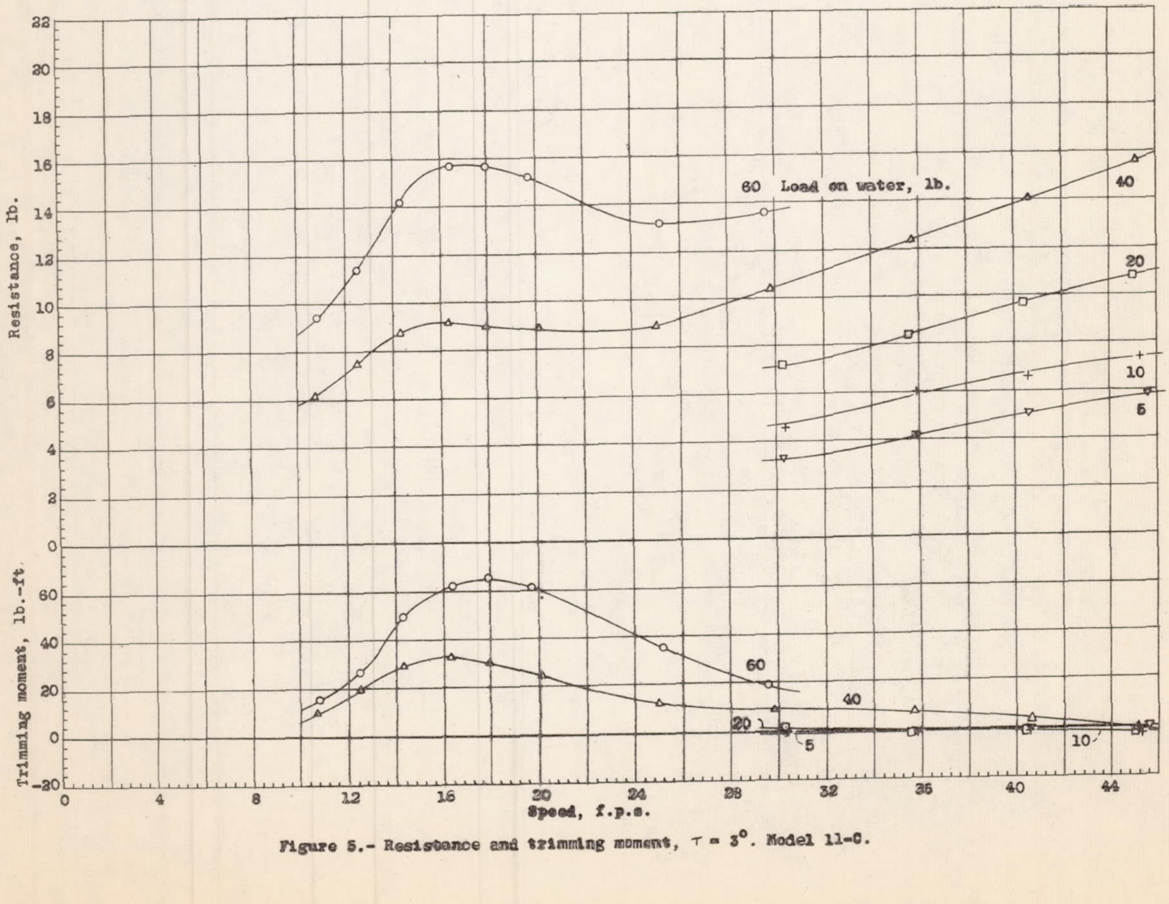


Figure 5.- Resistance and trimming moment, $\tau = 3^{\circ}$. Model 11-C.

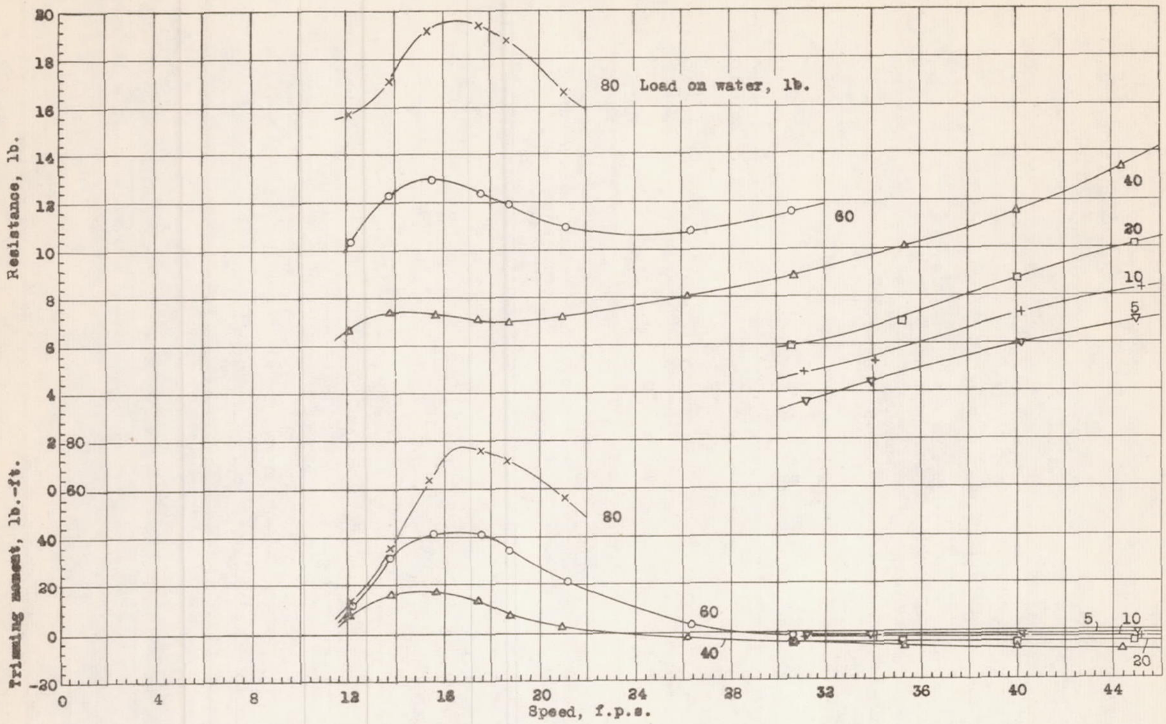


Figure 6.- Resistance and trimming moment, $\tau = 5^{\circ}$. Model 11-C.

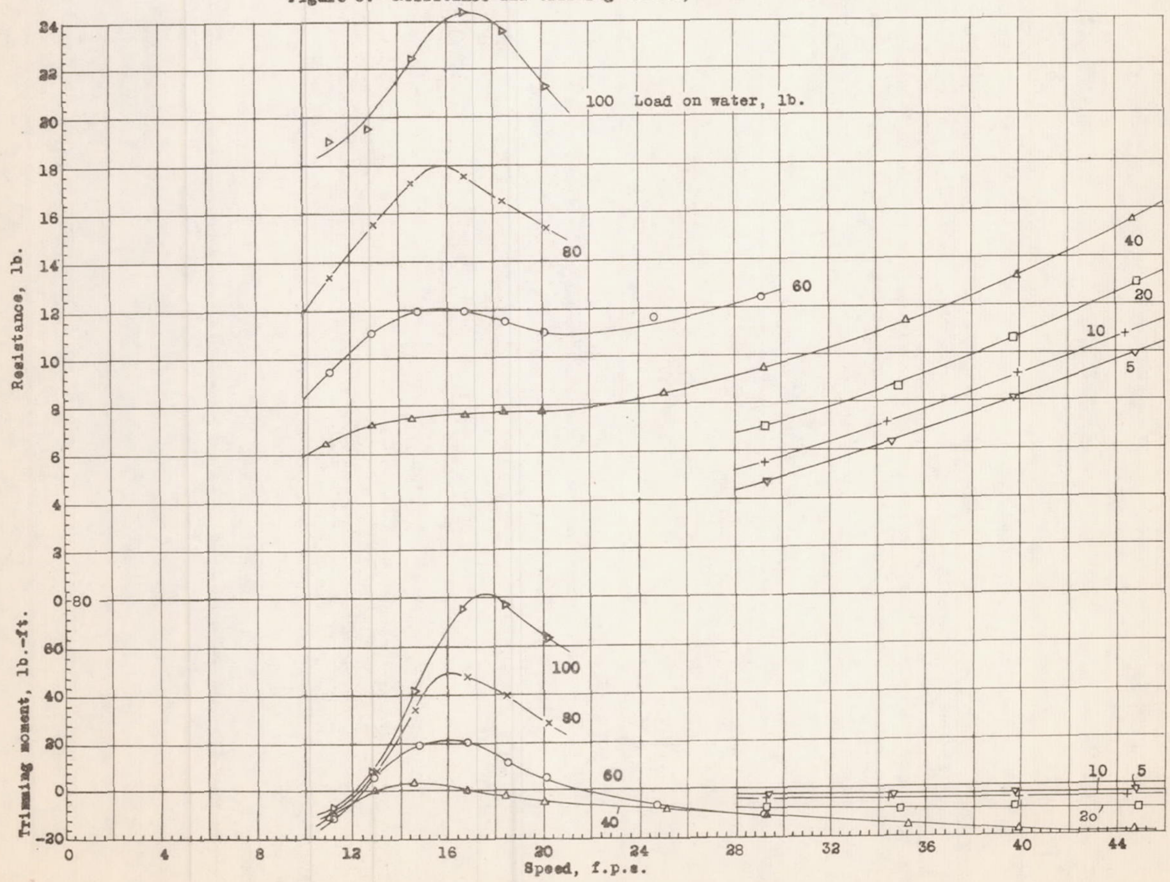


Figure 7.- Resistance and trimming moment, $\tau = 7^{\circ}$. Model 11-C.

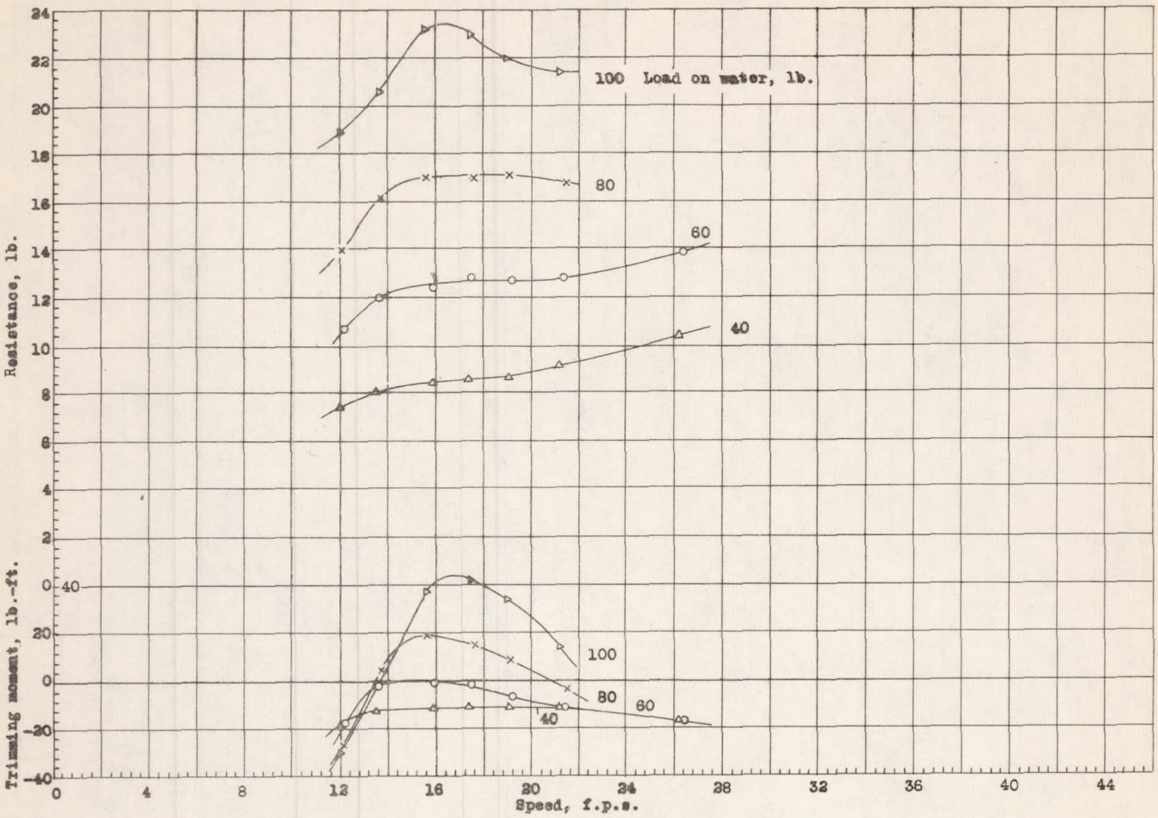


Figure 8.- Resistance and trimming moment, $\tau = 9^{o}$. Model 11-C

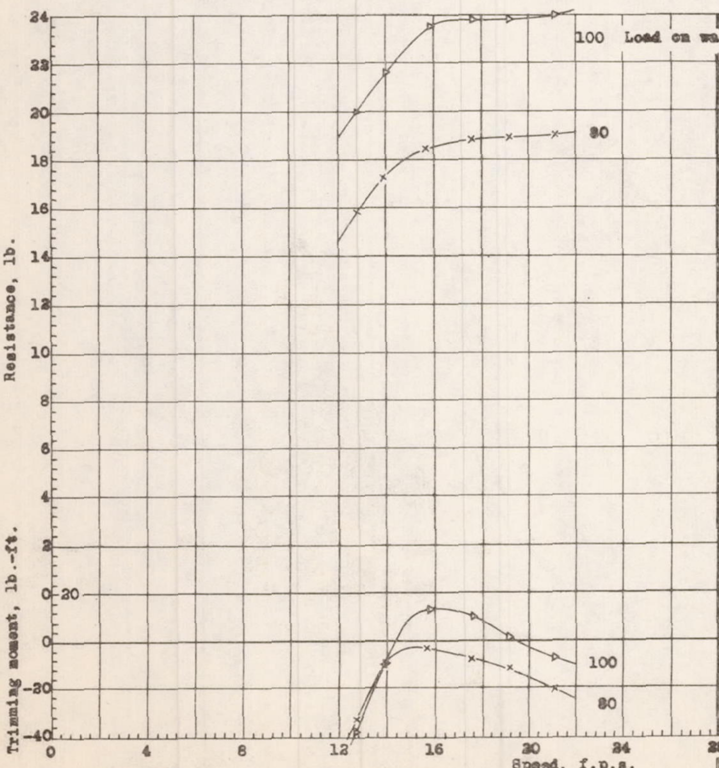


Figure 9.- Resistance and trimming moment, $\tau = 11^{o}$. Model 11-C.

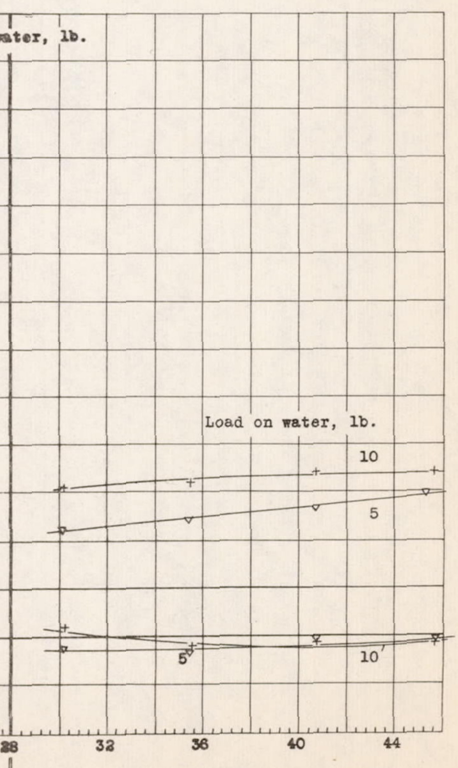


Figure 10.- Resistance and trimming moment, $\tau = 2^{o}$. Model 11-E.

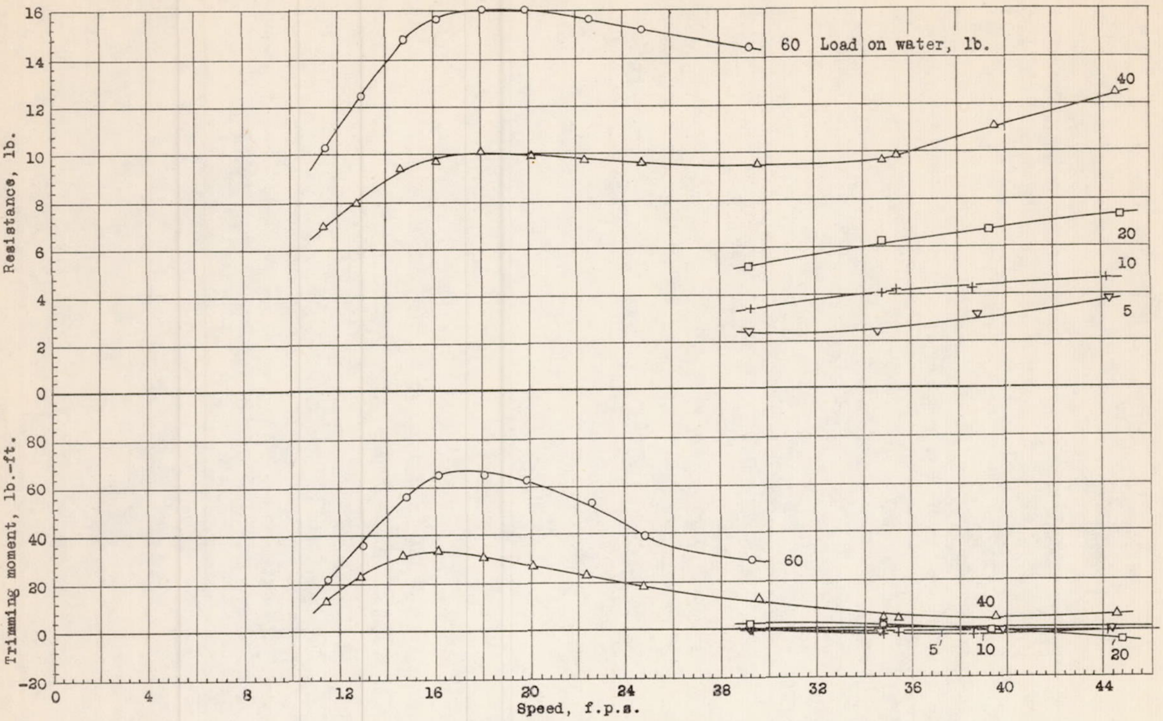


Figure 11.- Resistance and trimming moment, τ = 3°. Model 11-E.

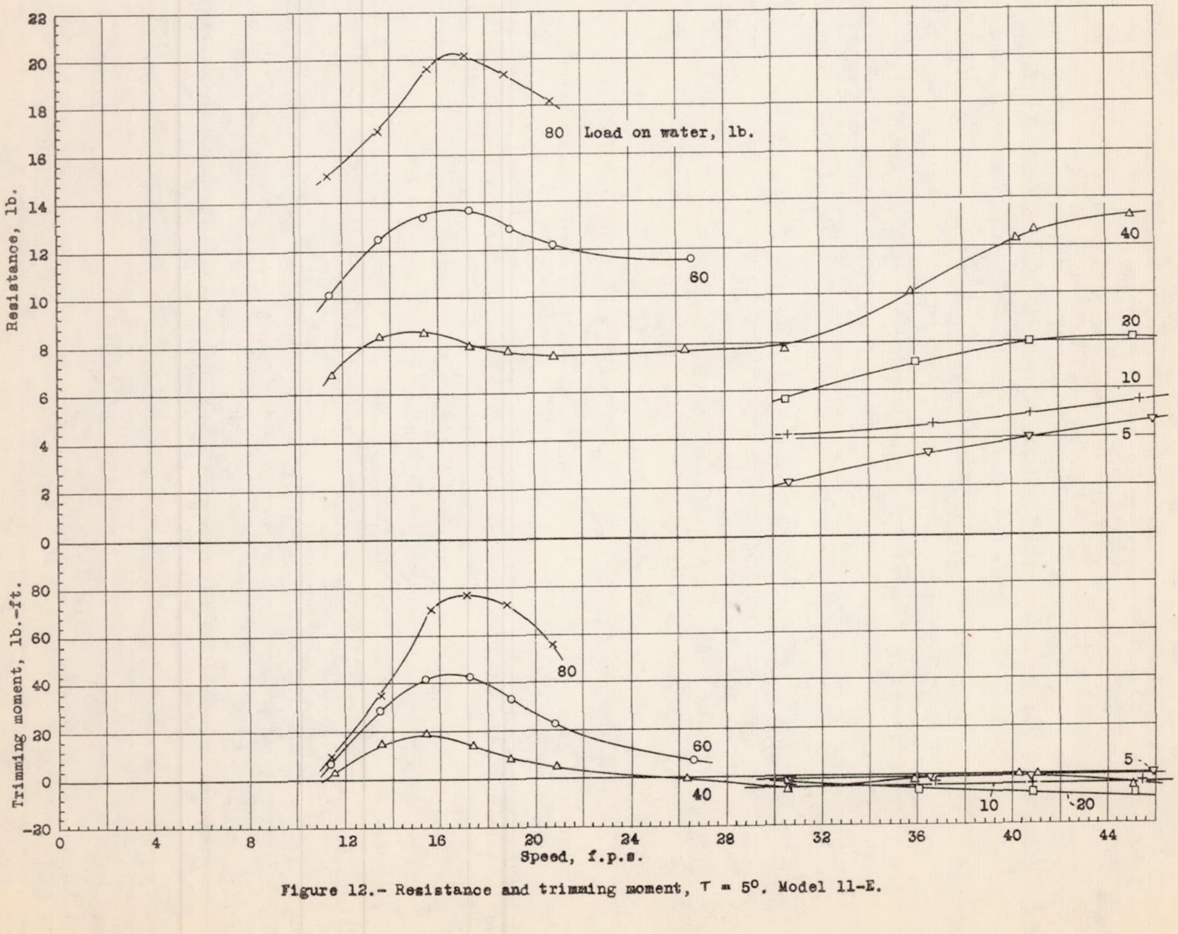


Figure 12.- Resistance and trimming moment, τ = 5°. Model 11-E.

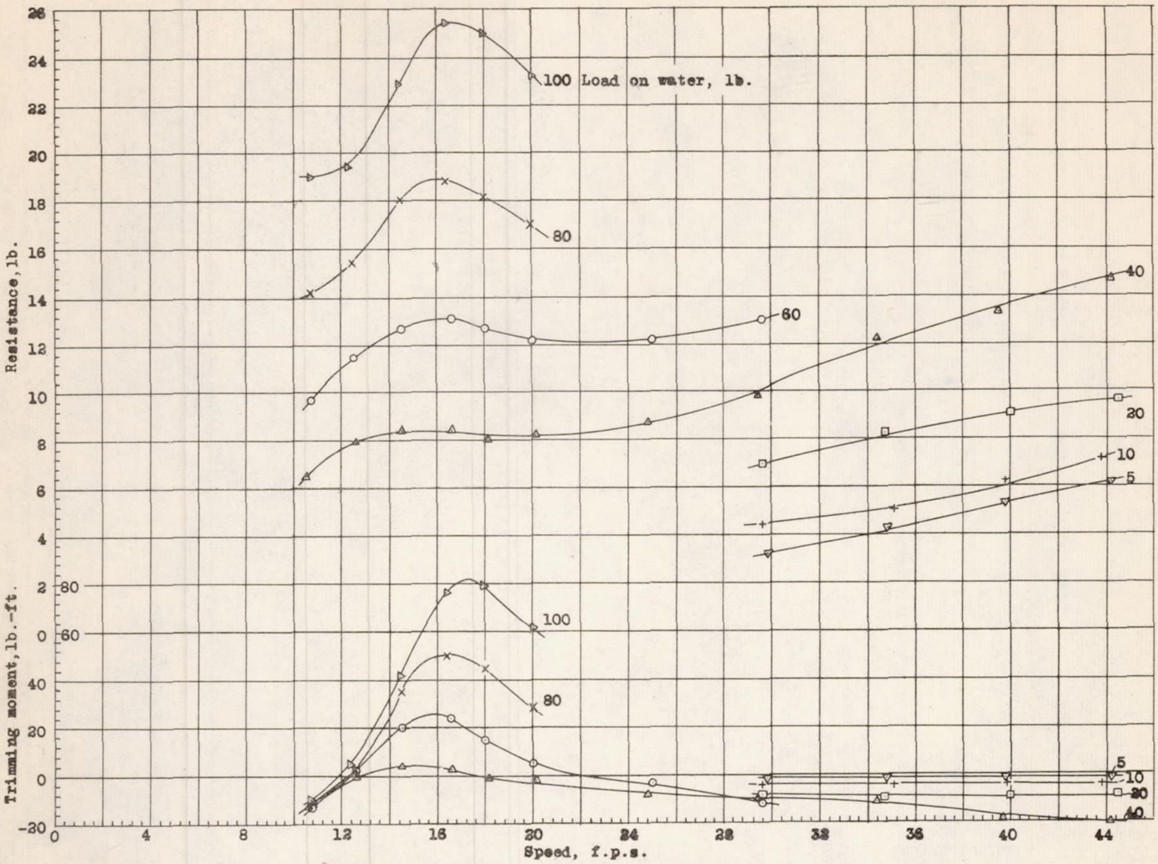


Figure 13.-Resistance and trimming moment, τ = 7°. Model 11-E.

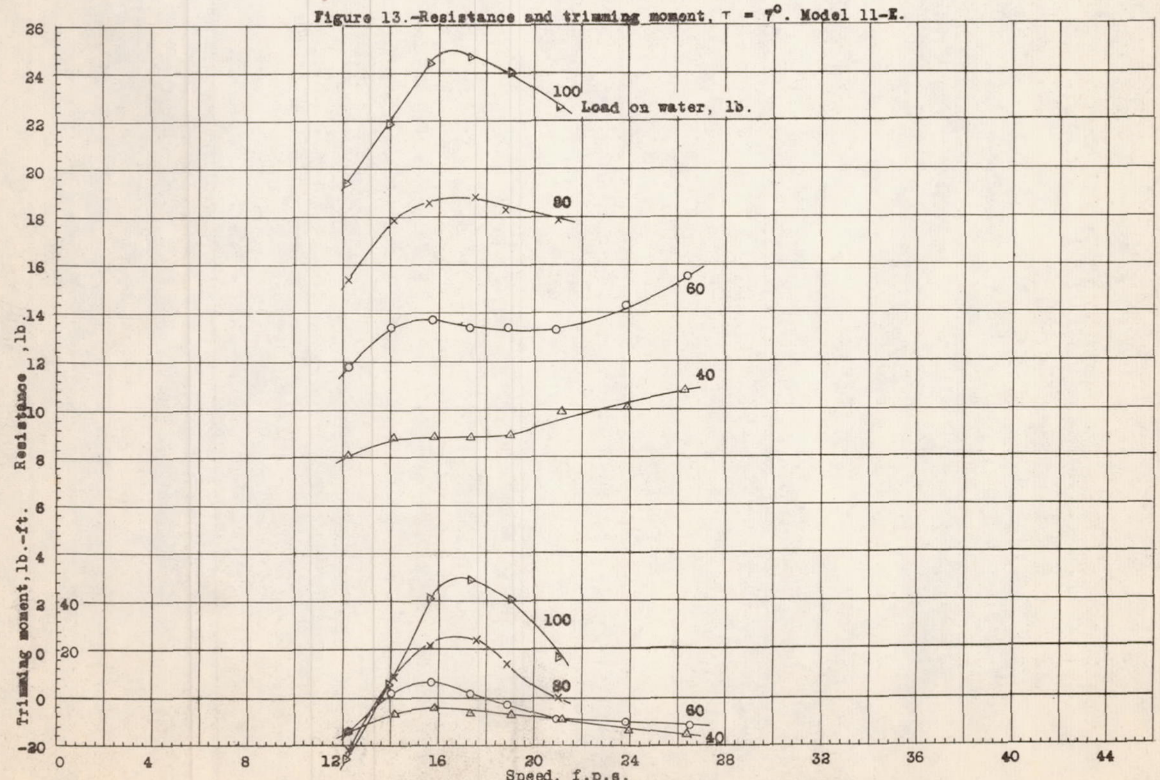


Figure 14.-Resistance and trimming moment, τ = 9°. Model 11-E.

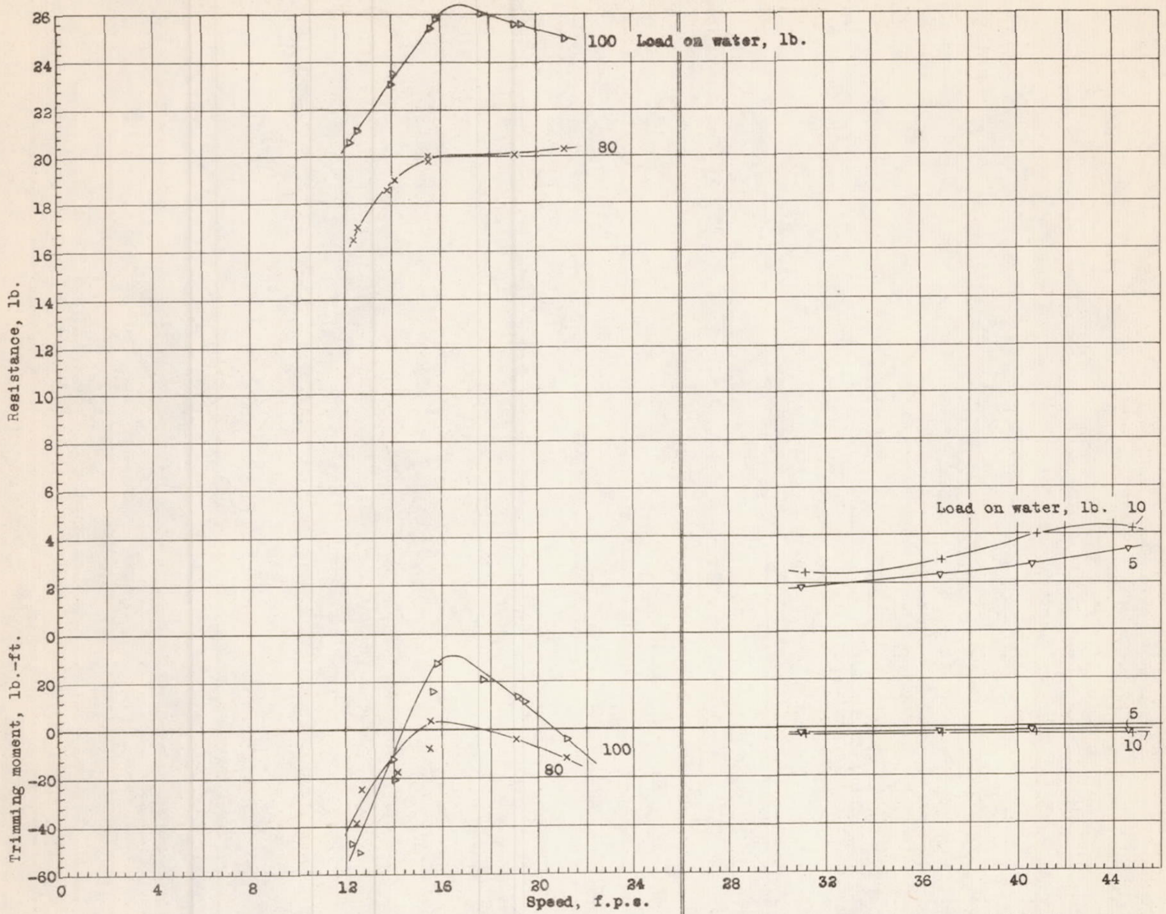


Figure 15.- Resistance and trimming moment, τ = 11°. Model 11-E

Figure 16.- Resistance and trimming moment, τ = 2°. Model 11-E-1.

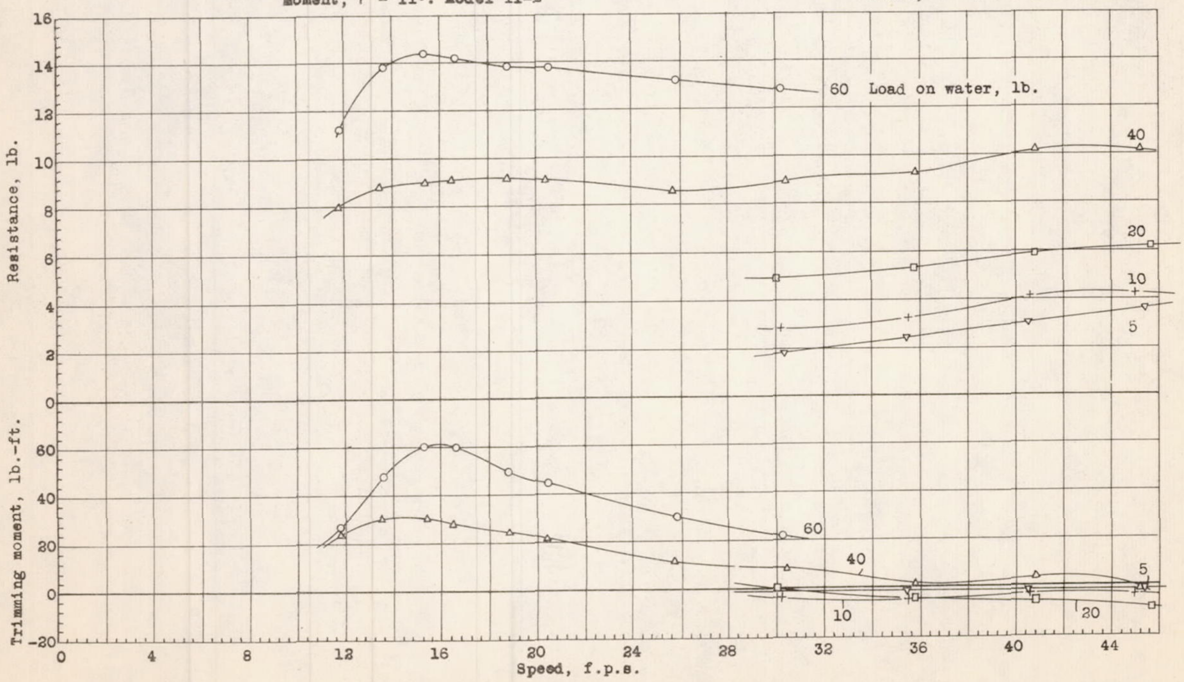


Figure 17.- Resistance and trimming moment, τ = 3°. Model 11-E-1.

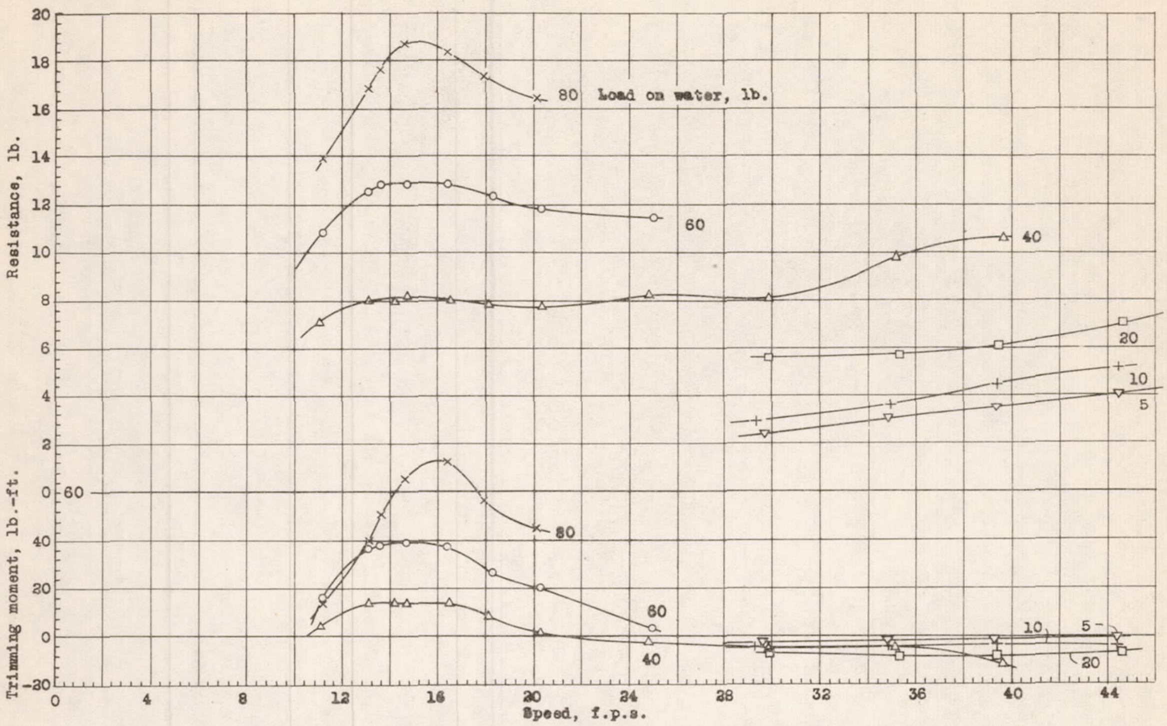


Figure 18.- Resistance and trimming moment, $\tau = 5^{\circ}$. Model 11-E-1.

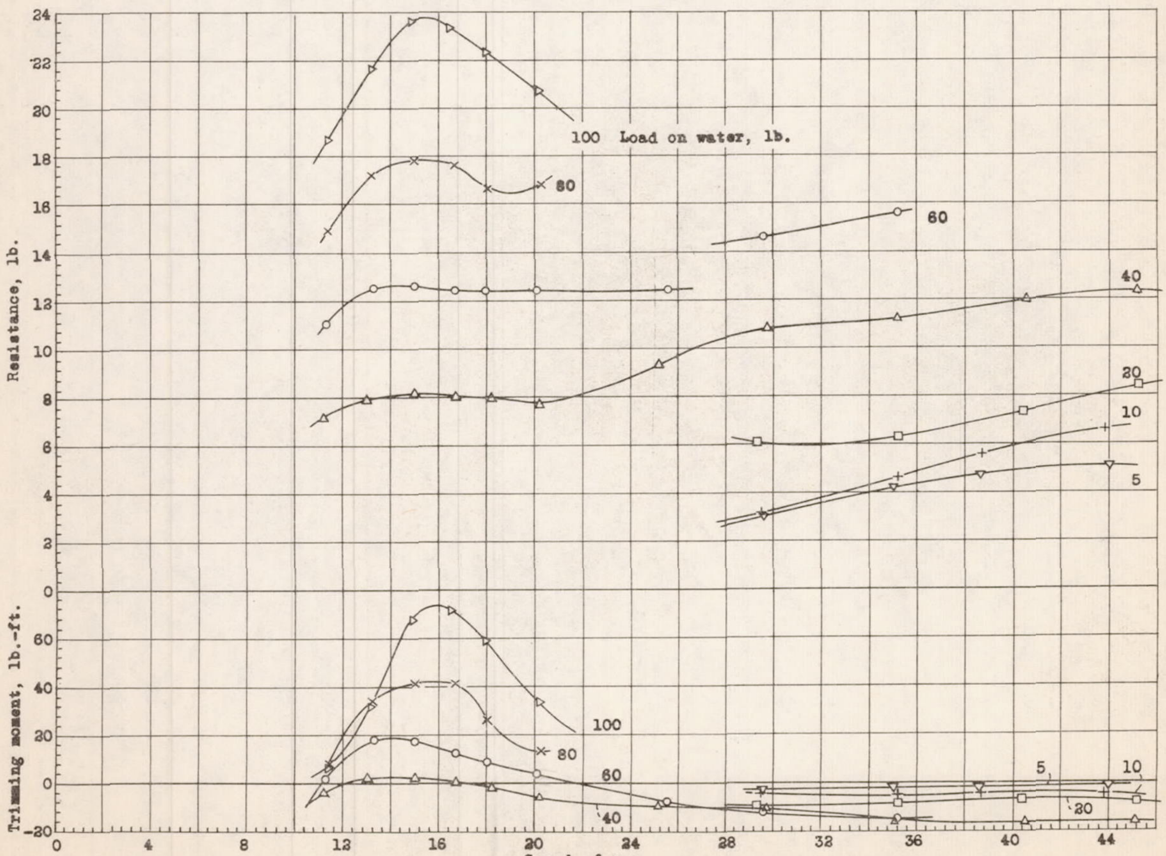


Figure 19.- Resistance and trimming moment, $\tau = 7^{\circ}$. Model 11-E-1.

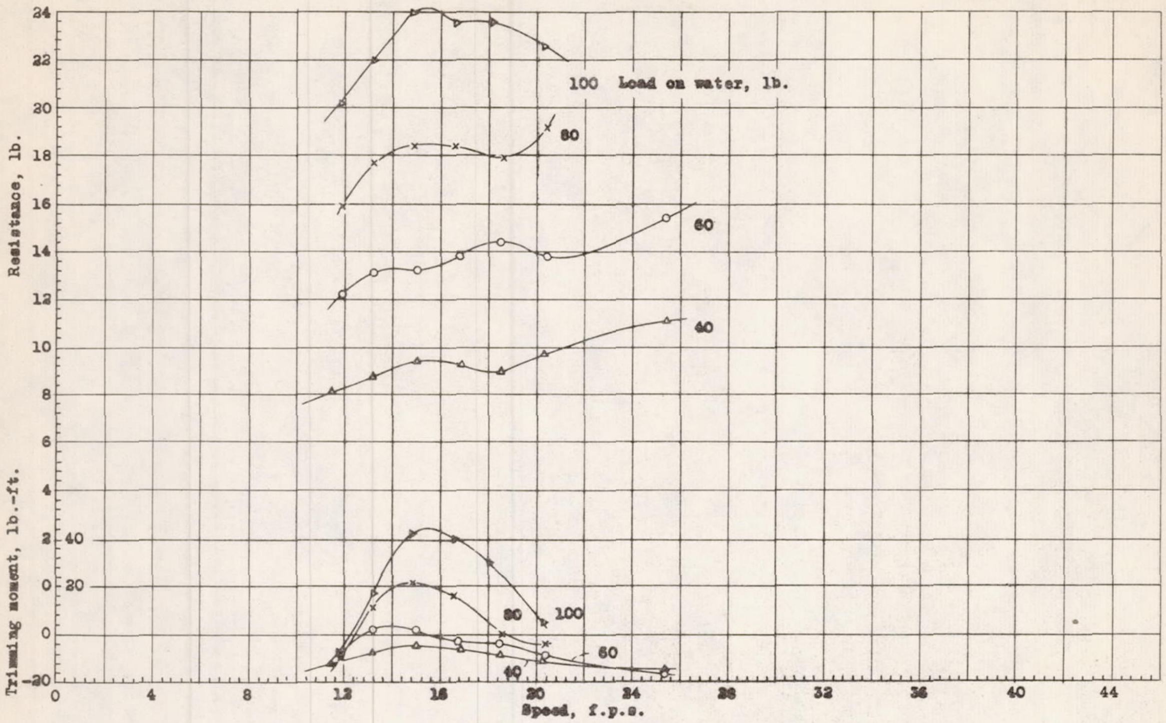


Figure 20.- Resistance and trimming moment, τ = 9°. Model 11-E-1.

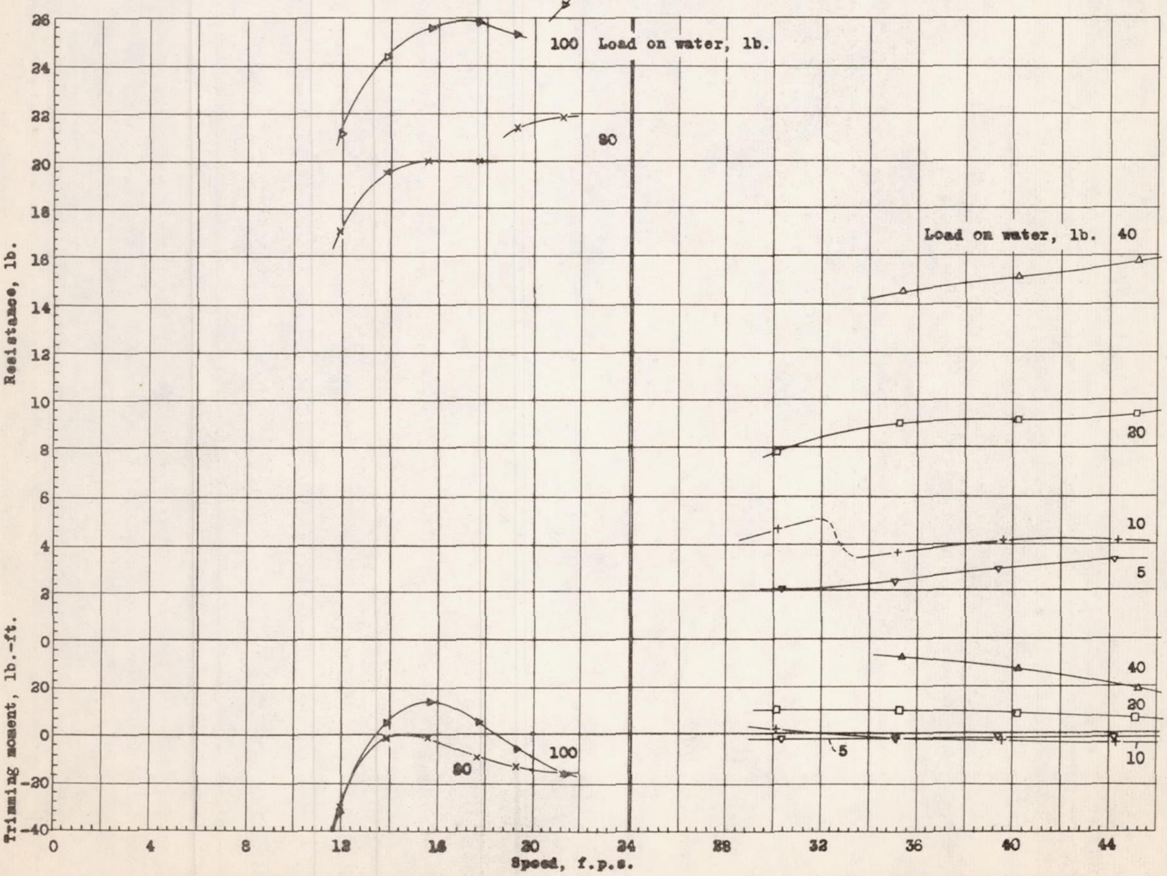


Figure 21.- Resistance and trimming moment, τ = 11°. Model 11-E-1.

Figure 22.- Resistance and trimming moment, τ = 1°. Model 11-E-2.

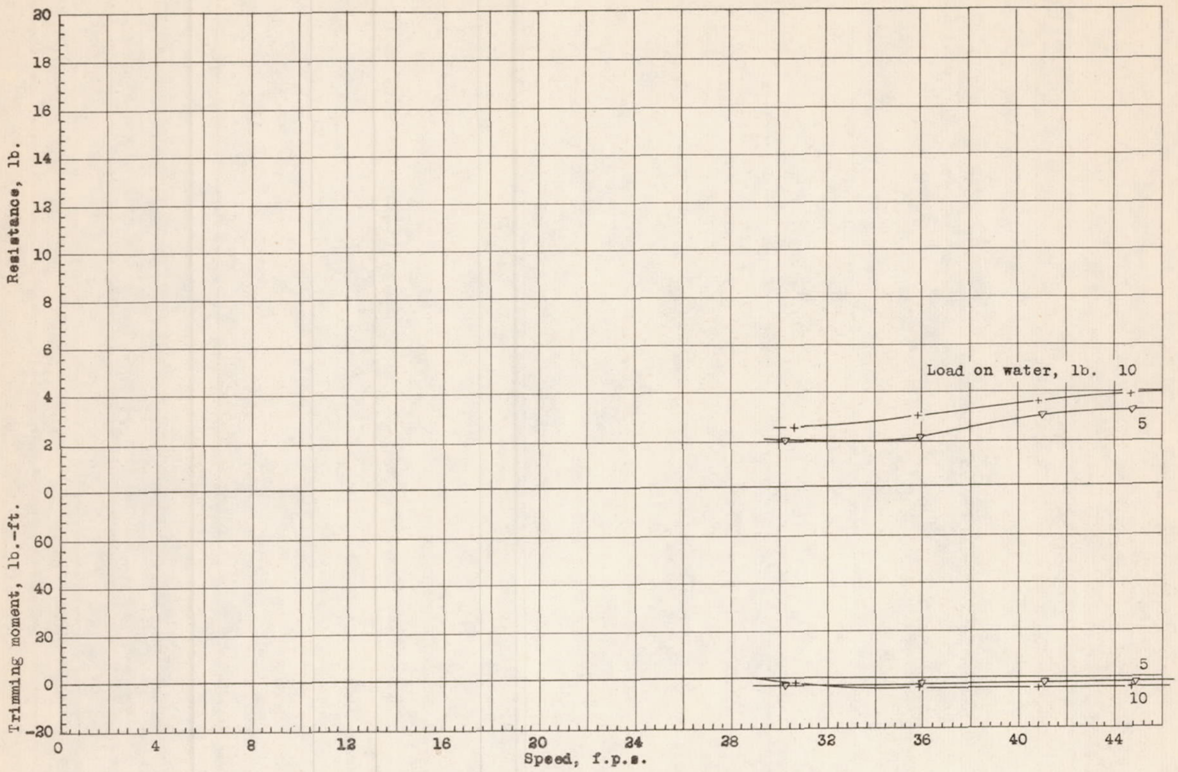


Figure 23.- Resistance and trimming moment, $\tau = 2^\circ$. Model 11-E-2.

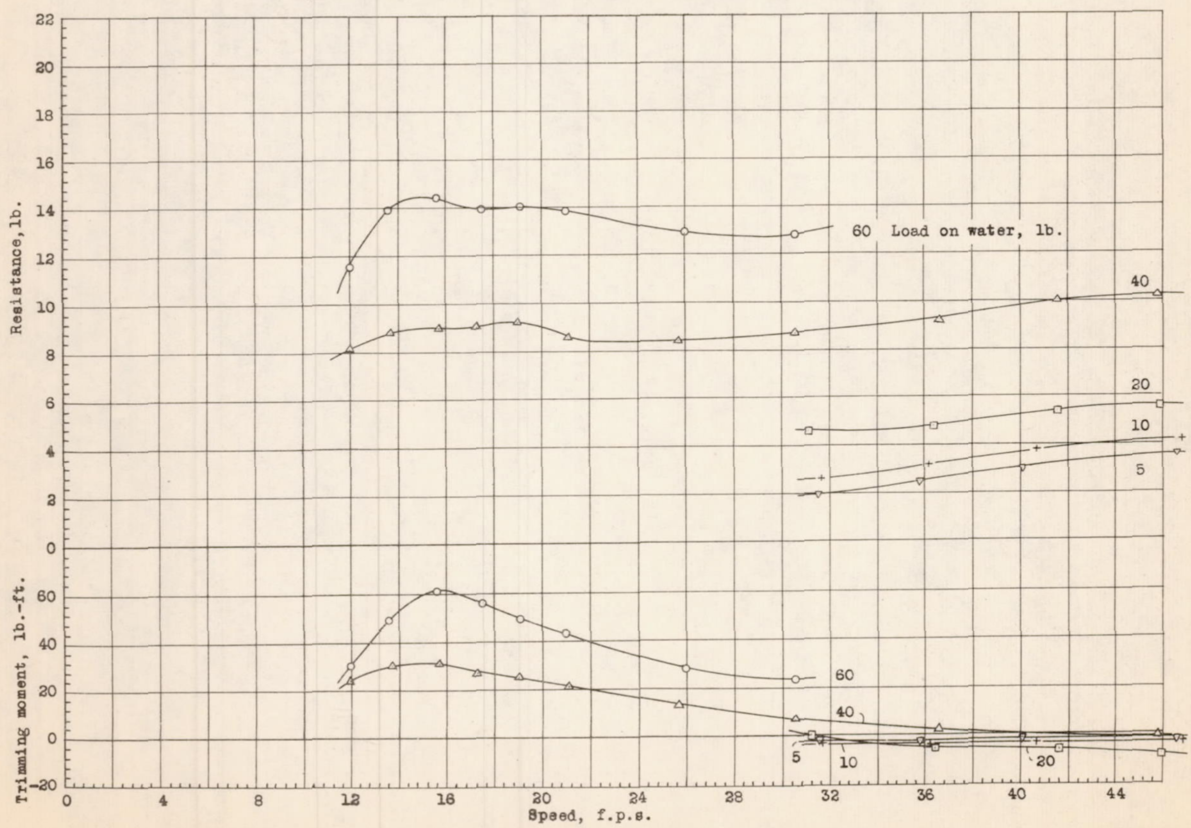


Figure 24.- Resistance and trimming moment, $\tau = 3^\circ$. Model 11-E-2.

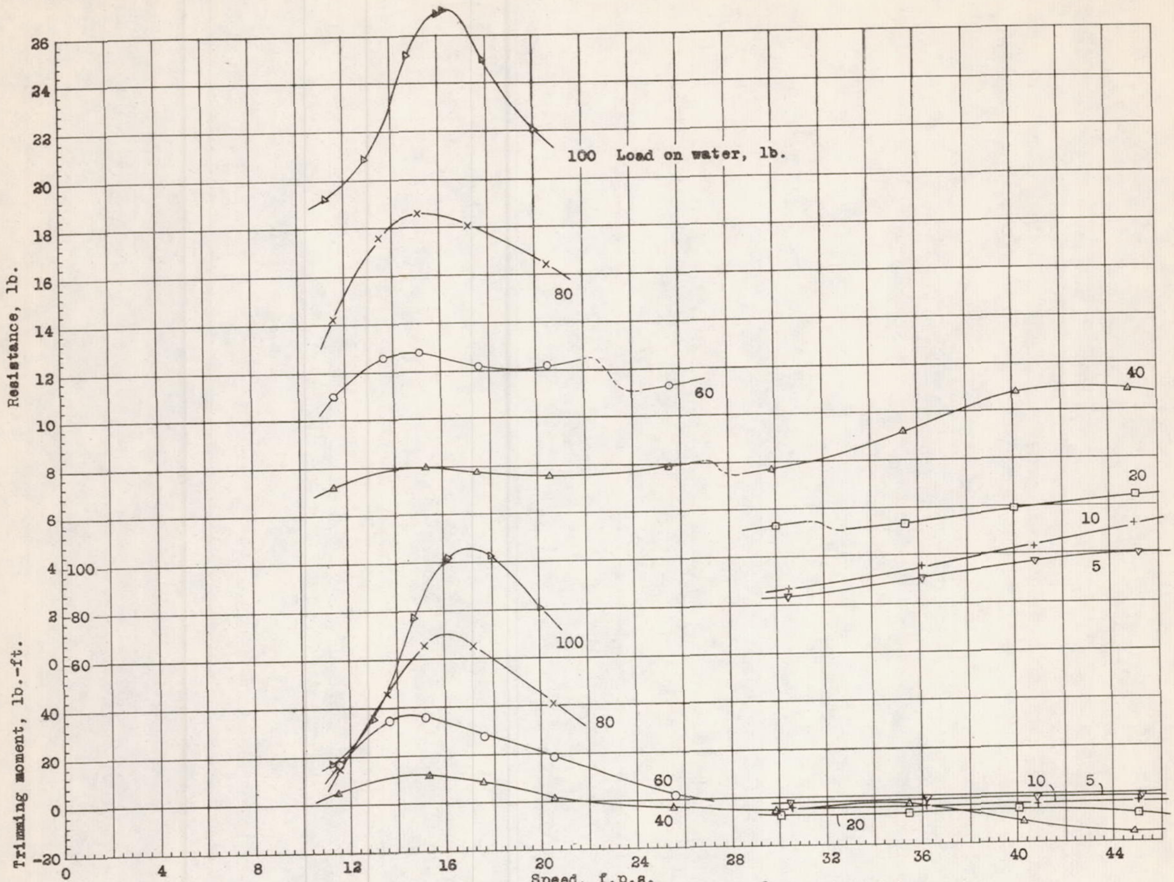


Figure 25.- Resistance and trimming moment, $\tau = 5^{\circ}$. Model 11-E-2.

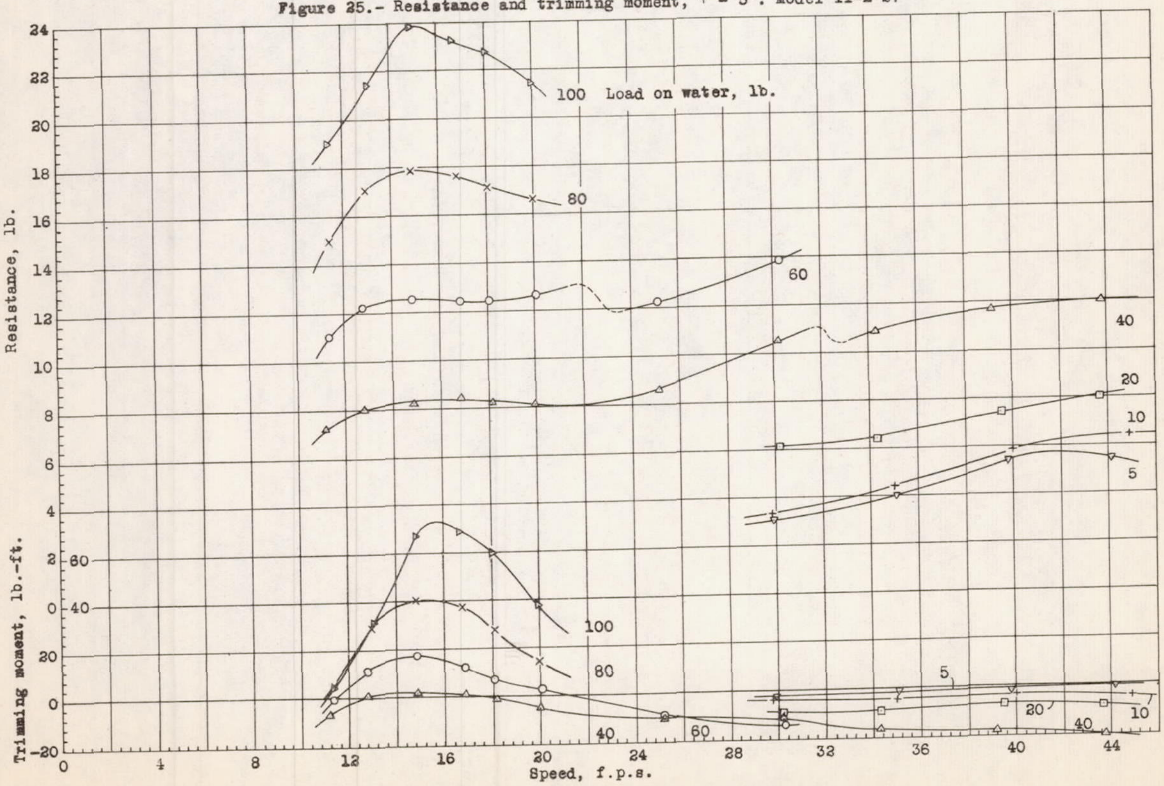


Figure 26.- Resistance and trimming moment, $\tau = 7^{\circ}$. Model 11-E-2.

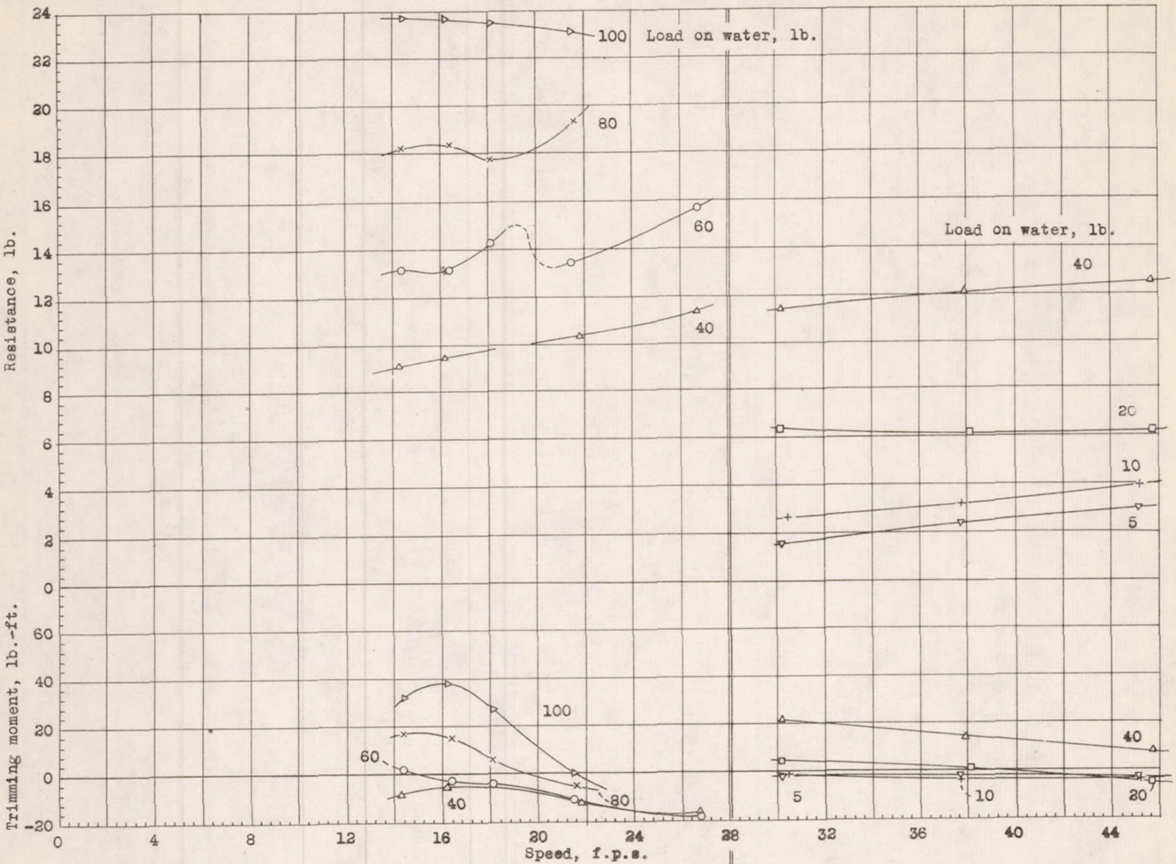


Figure 27.- Resistance and trimming moment, τ = 9°. Model 11-E-3.

Figure 28.- Resistance and trimming moment, τ = 2°. Model 11-E-3

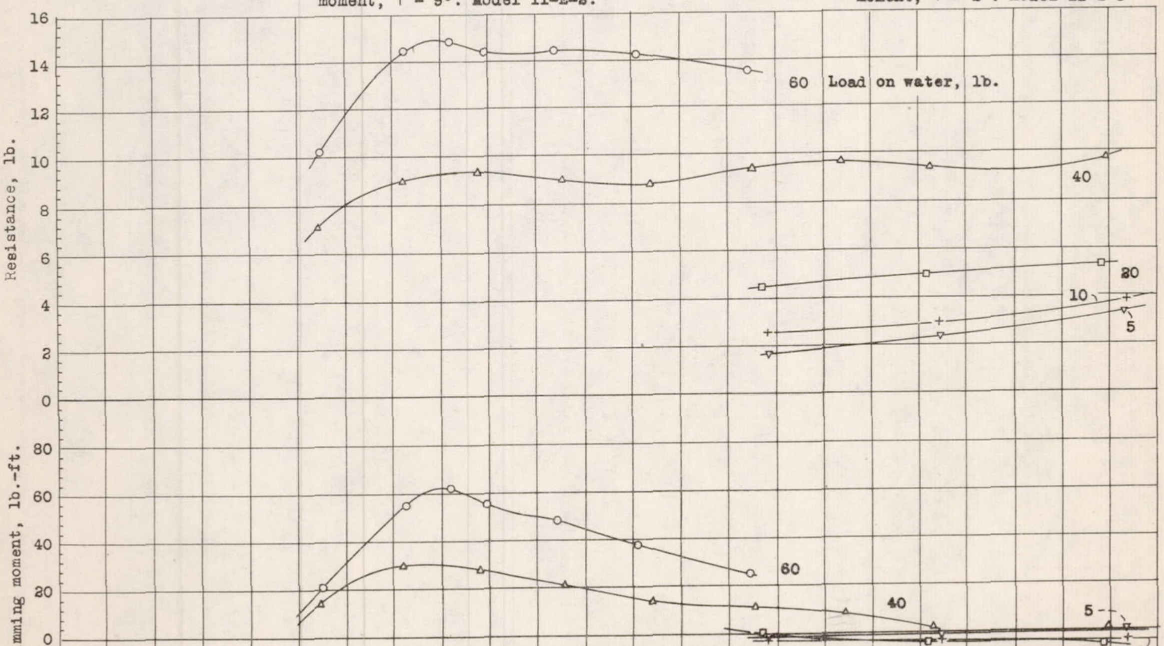


Figure 29.- Resistance and trimming moment, τ = 3°. Model 11-E-3.

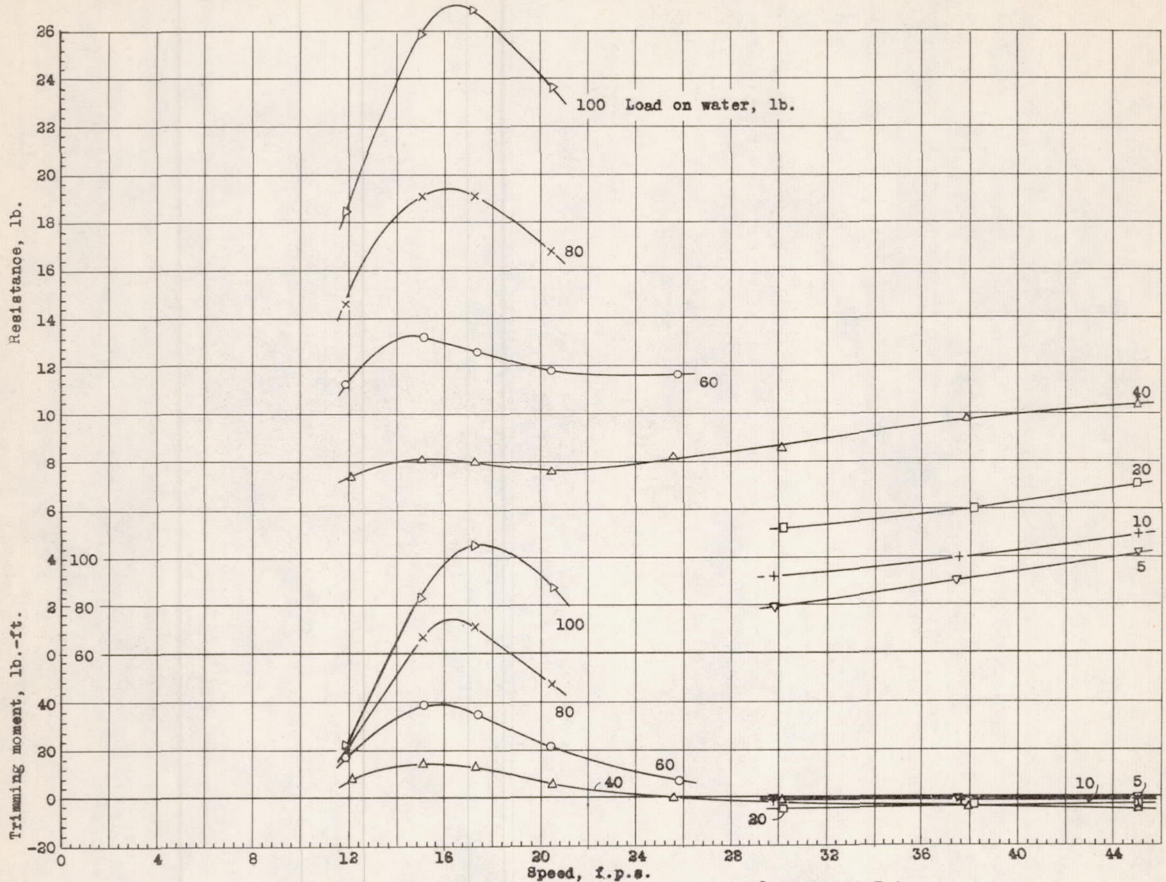


Figure 35.- Resistance and trimming moment, $\tau = 5^{\circ}$. Model 11-E-4.

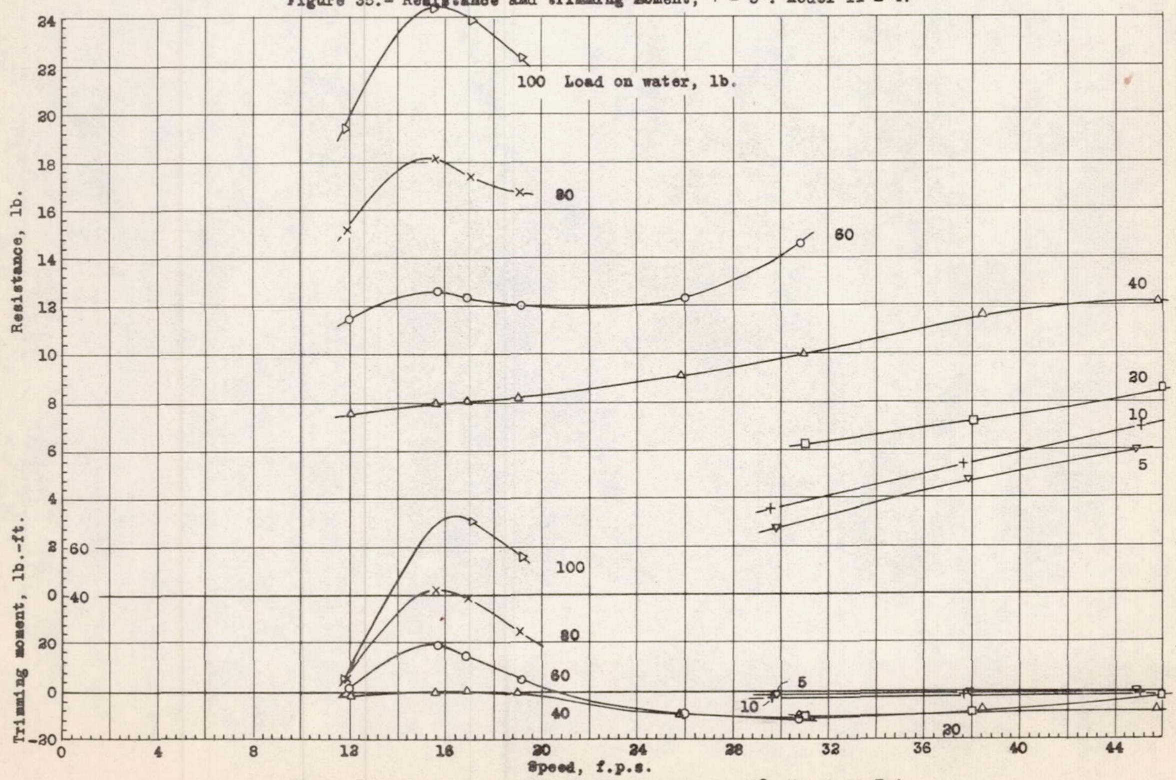


Figure 36.- Resistance and trimming moment, $\tau = 7^{\circ}$. Model 11-E-4.

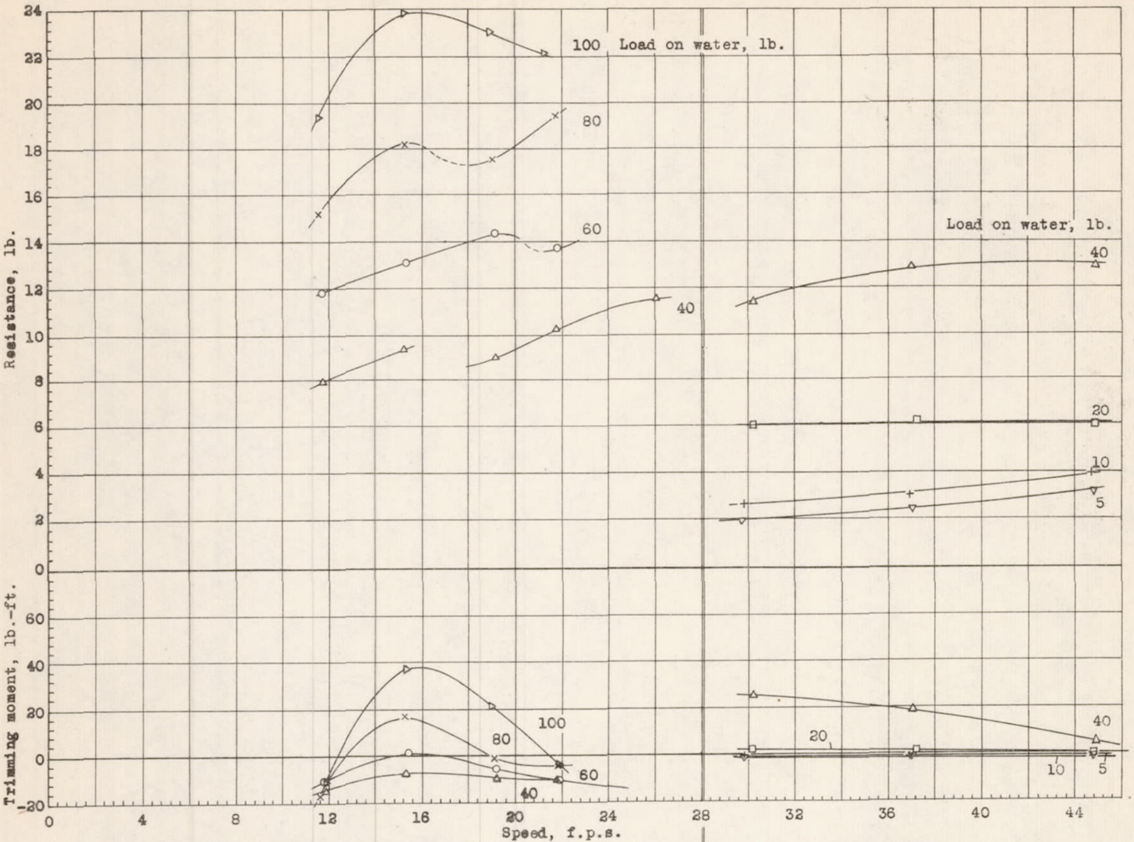


Figure 32.- Resistance and trimming moment, τ = 9°. Model 11-E-3.

Figure 33.- Resistance and trimming moment, τ = 2°. Model 11-E-4.

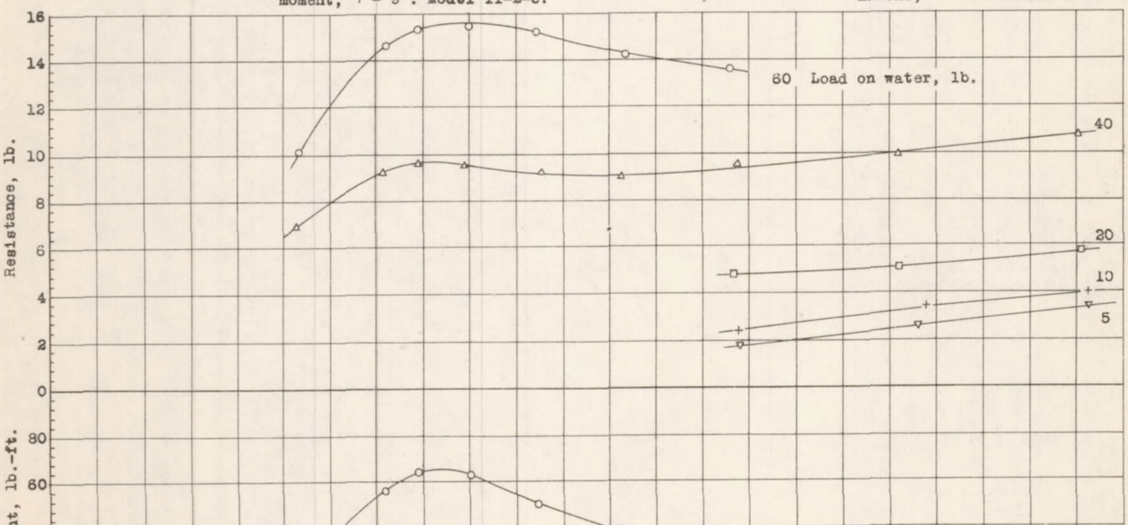


Figure 34.- Resistance and trimming moment, τ = 3°. Model 11-E-4.

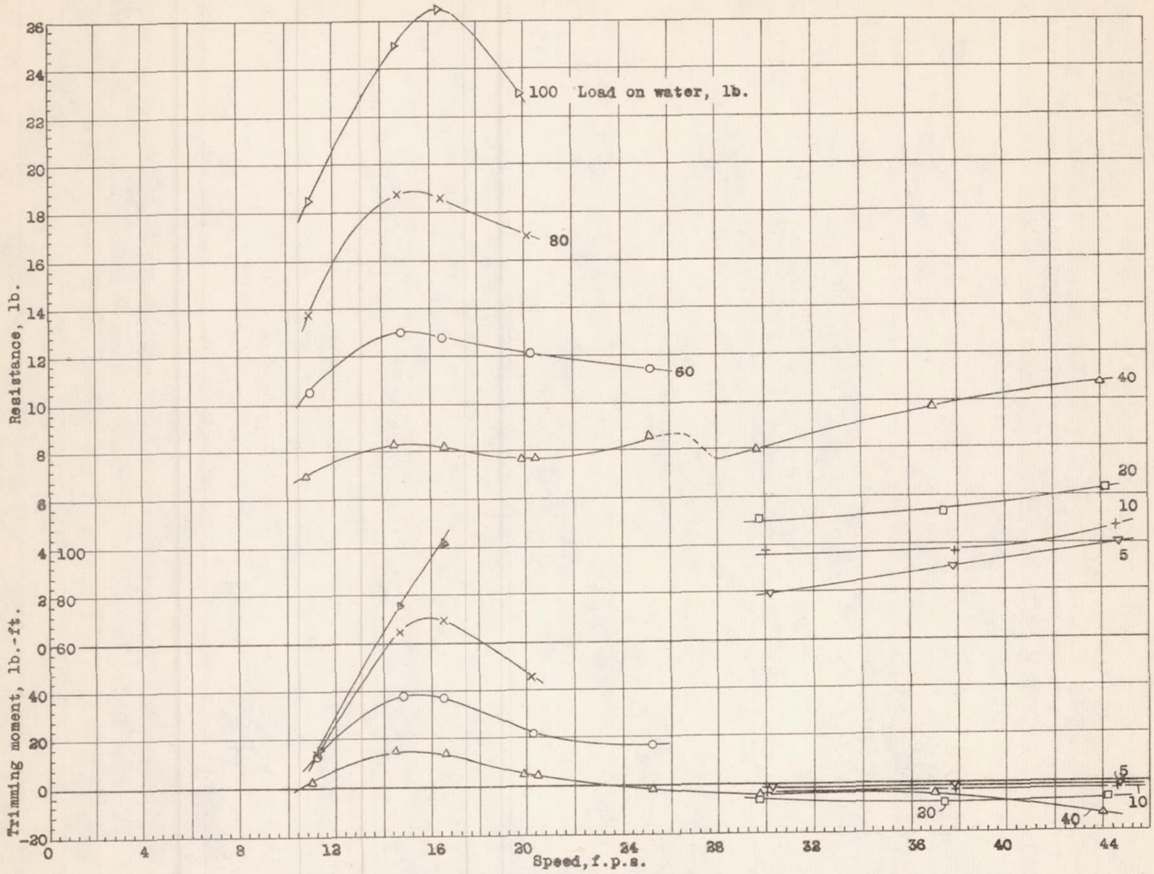


Figure 30.-Resistance and trimming moment, $\tau = 5^{\circ}$. Model 11-E-3.

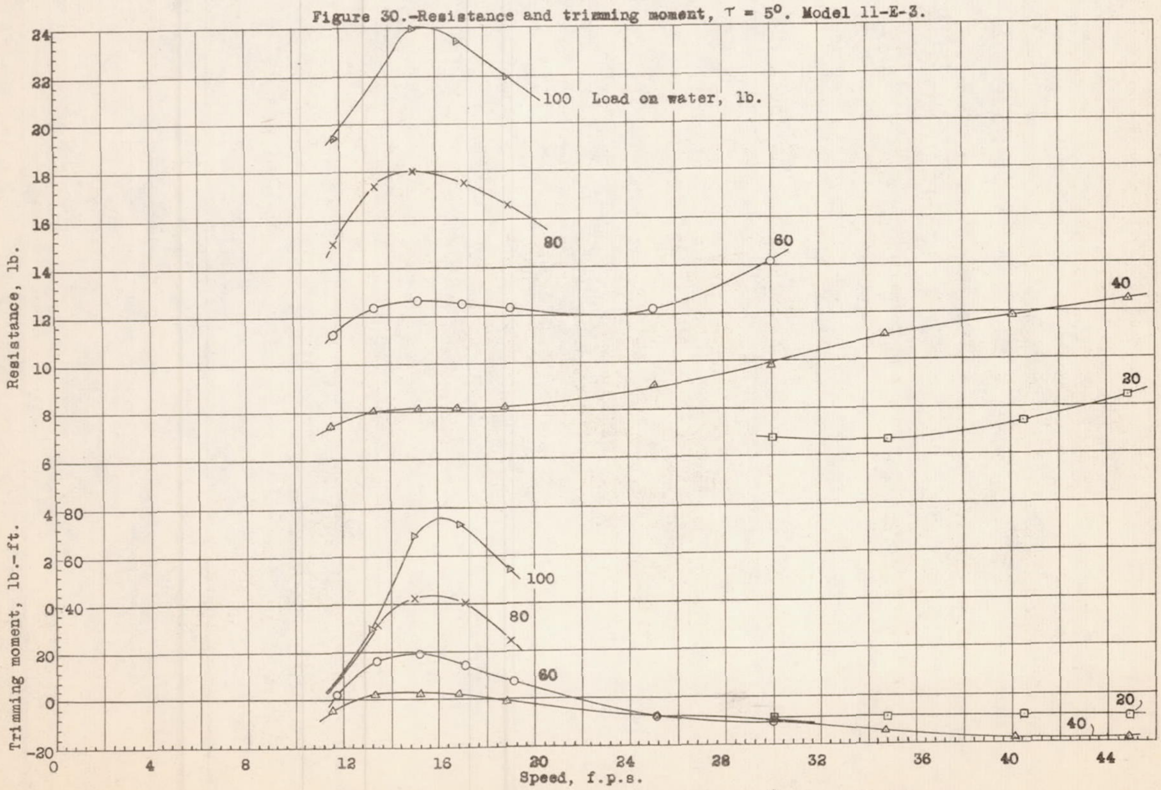


Figure 31.-Resistance and trimming moment, $\tau = 7^{\circ}$. Model 11-E-3.

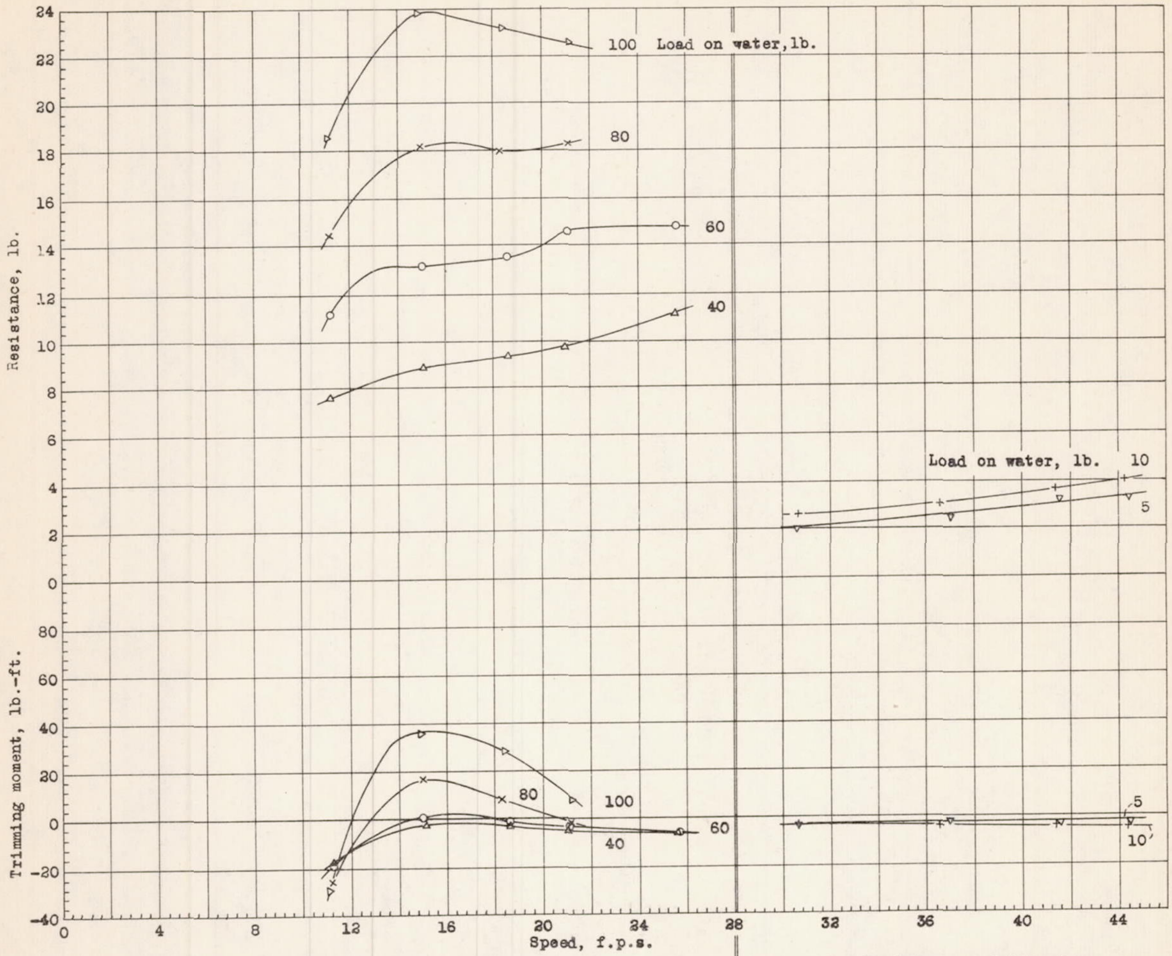


Figure 37.- Resistance and trimming moment, $\tau = 9^{0}$. Model 11-E-4.

Figure 38.- Resistance and trimming moment, $\tau = 2^{0}$. Model 11-E-5

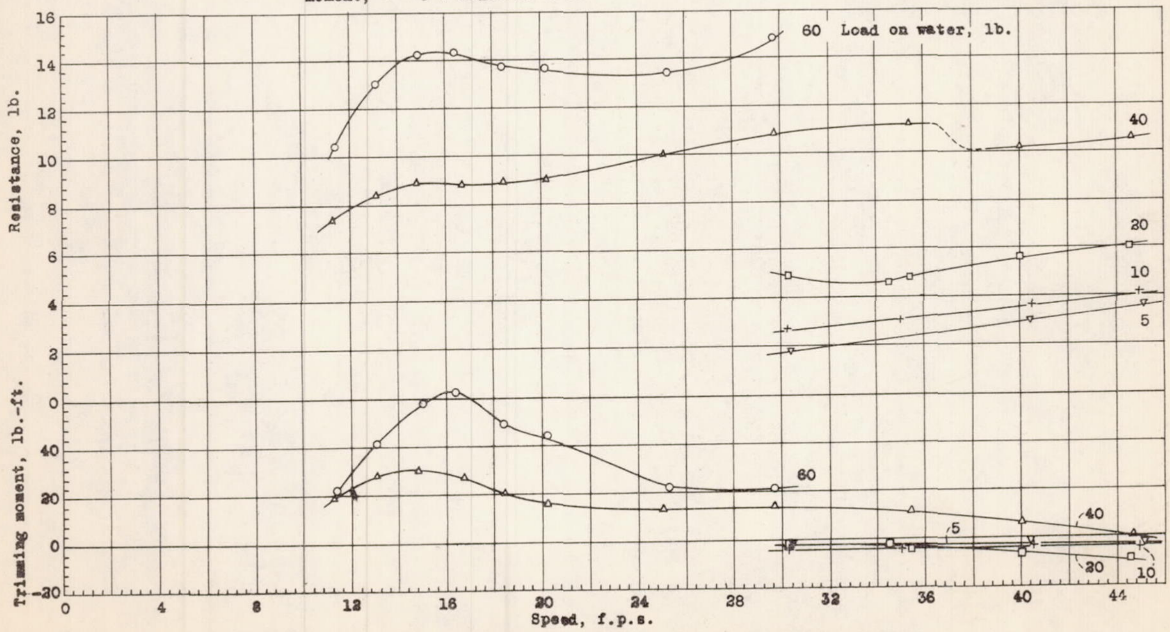


Figure 39.- Resistance and trimming moment, $\tau = 3^{0}$. Model 11-E-5.

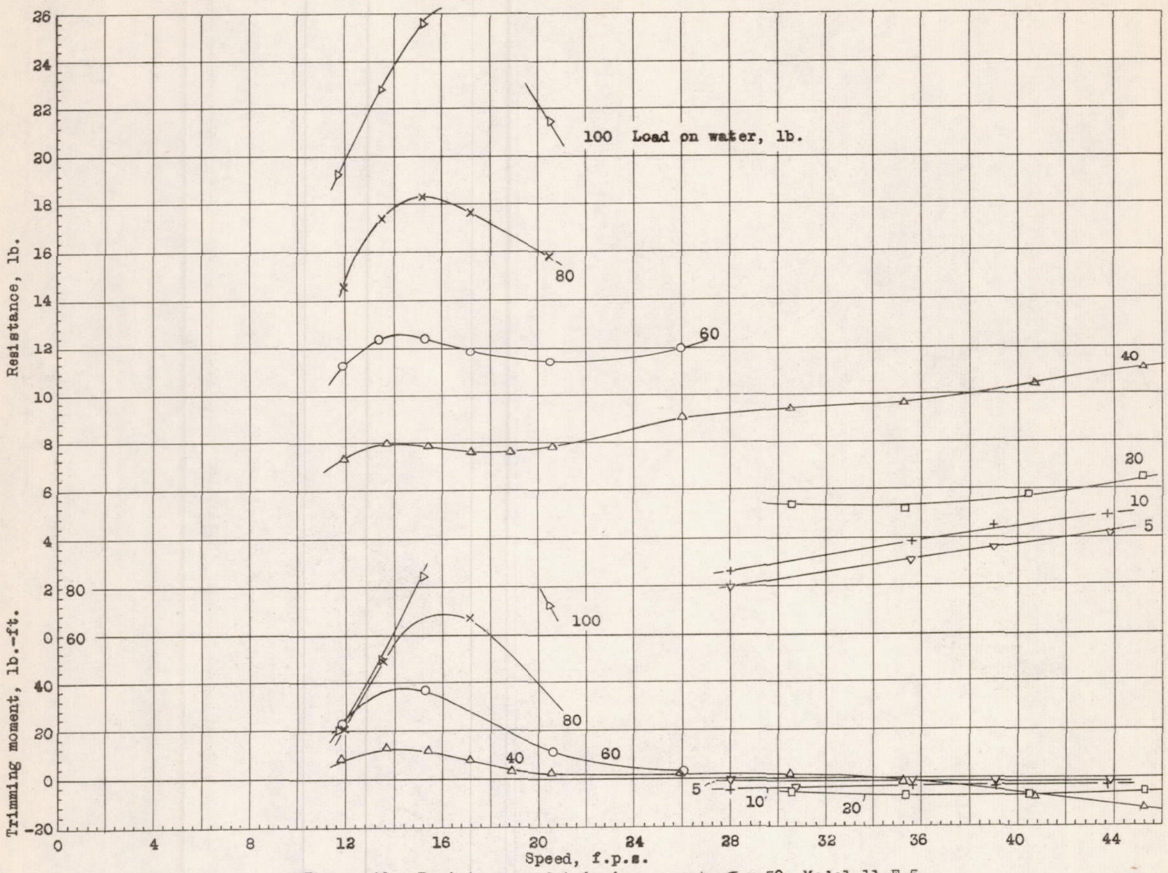


Figure 40.- Resistance and trimming moment, $\tau = 5^{o}$. Model 11-E-5.

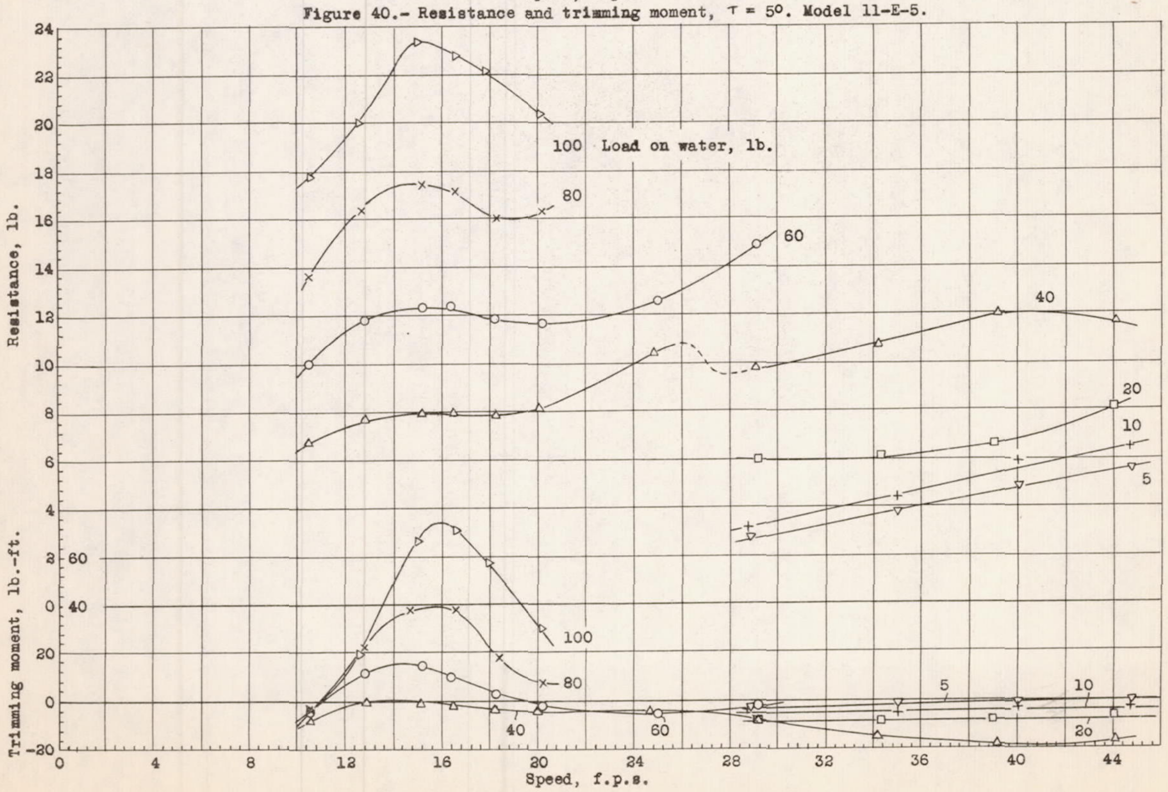


Figure 41.- Resistance and trimming moment, $\tau = 7^{o}$. Model 11-E-5.

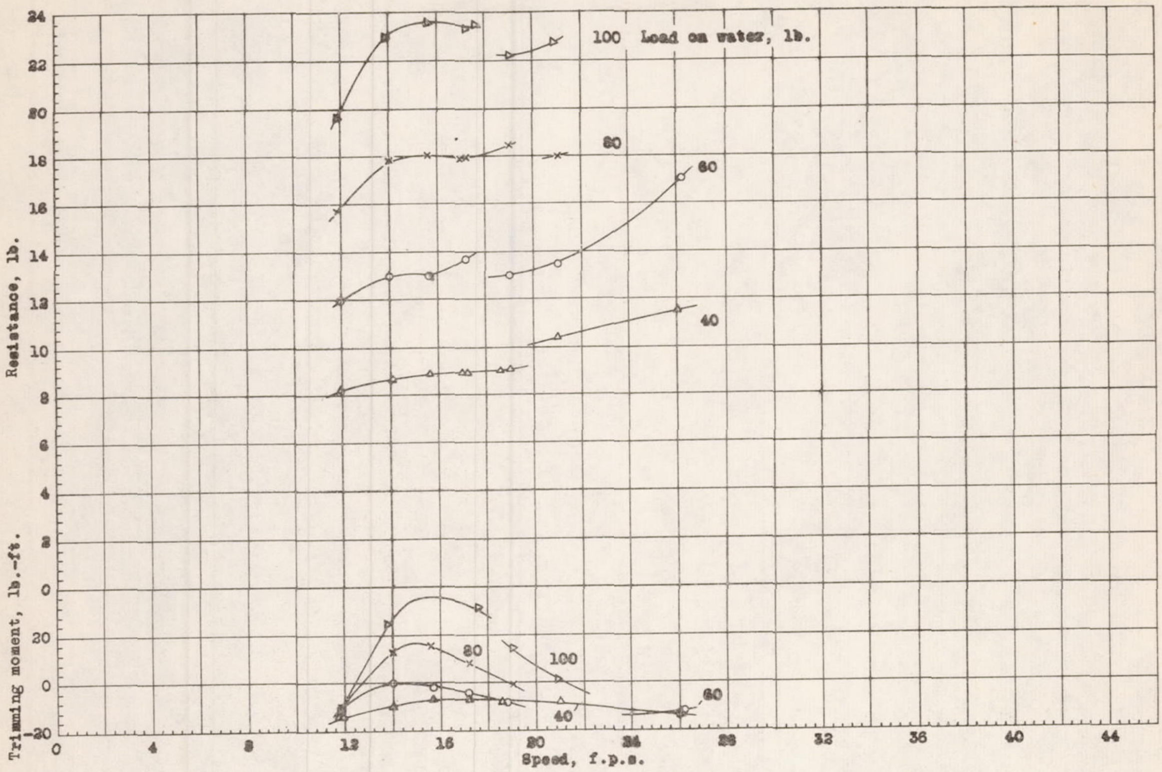


Figure 42.- Resistance and trimming moment, τ = 9°. Model 11-E-5.

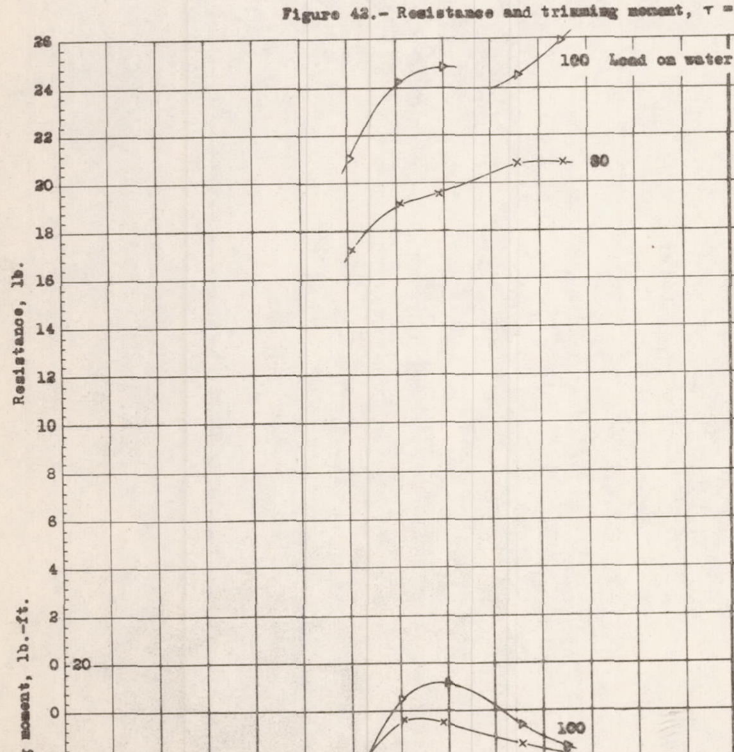


Figure 43.- Resistance and trimming moment, τ = 11°. Model 11-E-5.

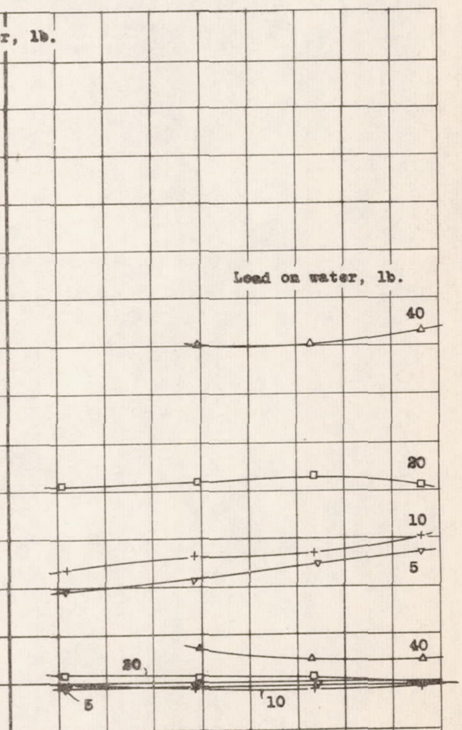


Figure 44.- Resistance and trimming moment, τ = 2°. Model 11-E-6.

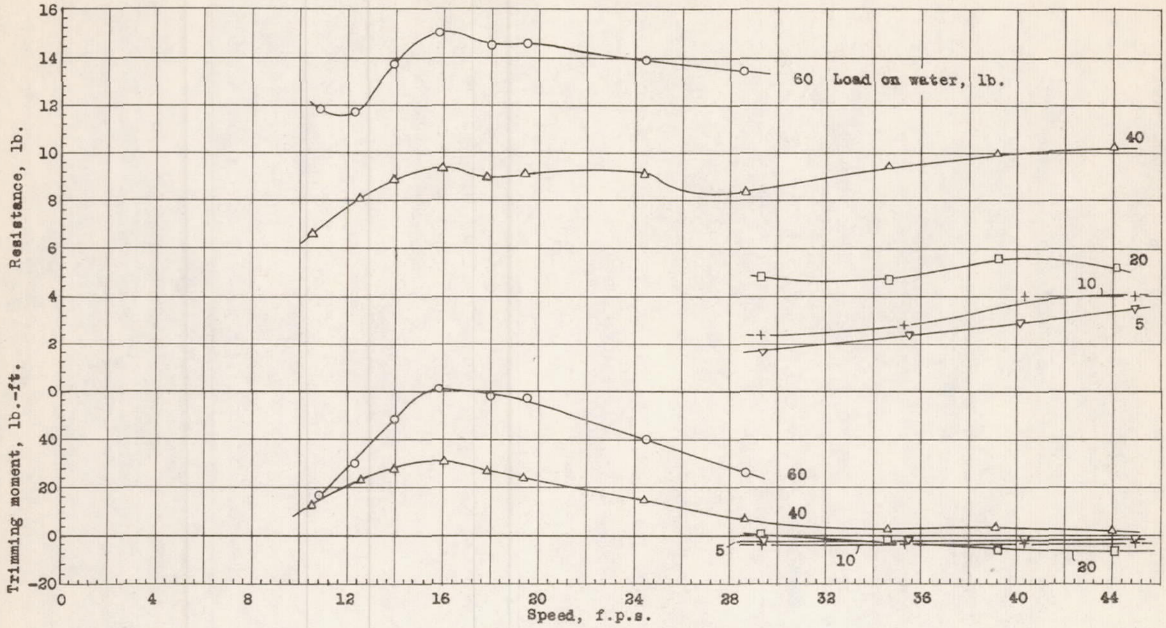


Figure 45.- Resistance and trimming moment, τ = 3°. Model 11-E-6.

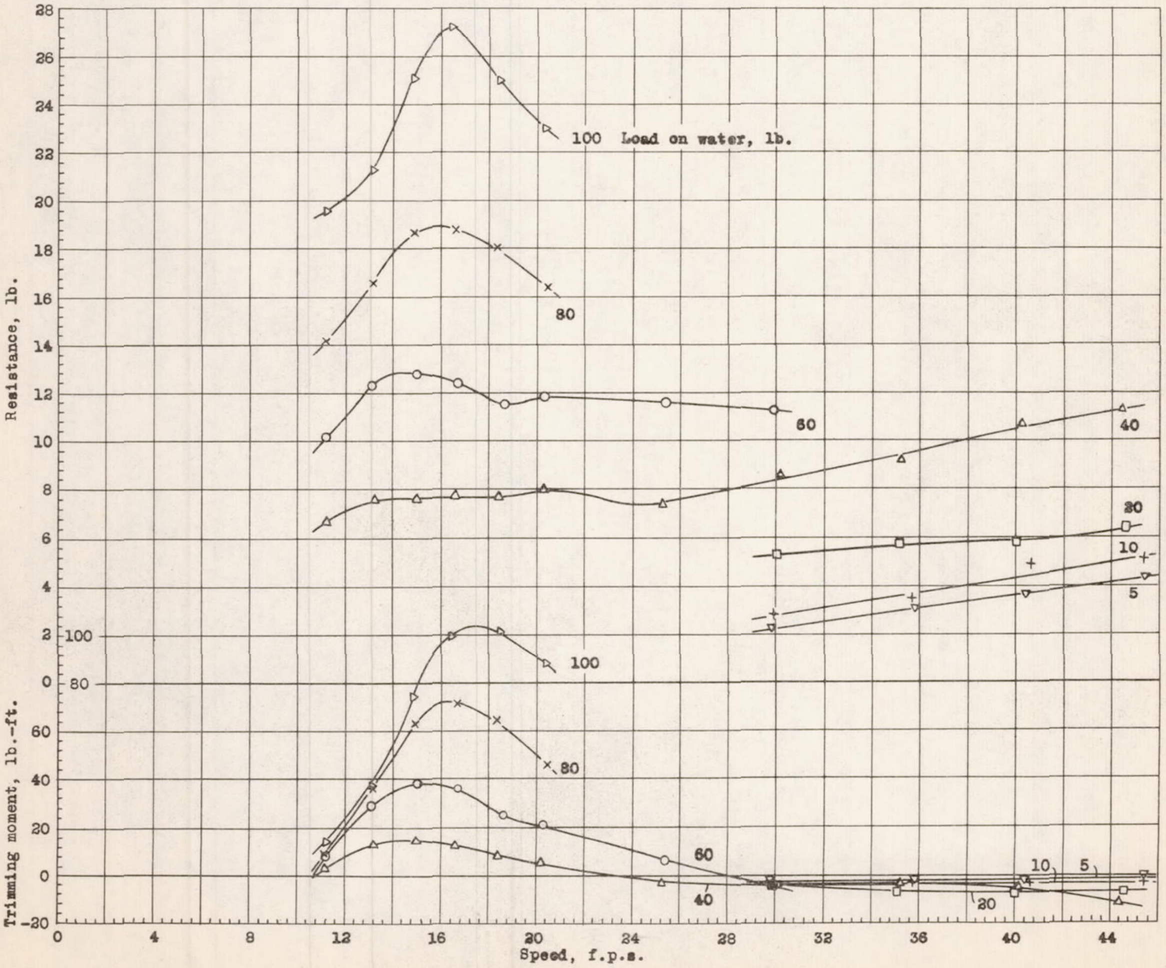


Figure 46.- Resistance and trimming moment, τ = 5°. Model 11-E-6.

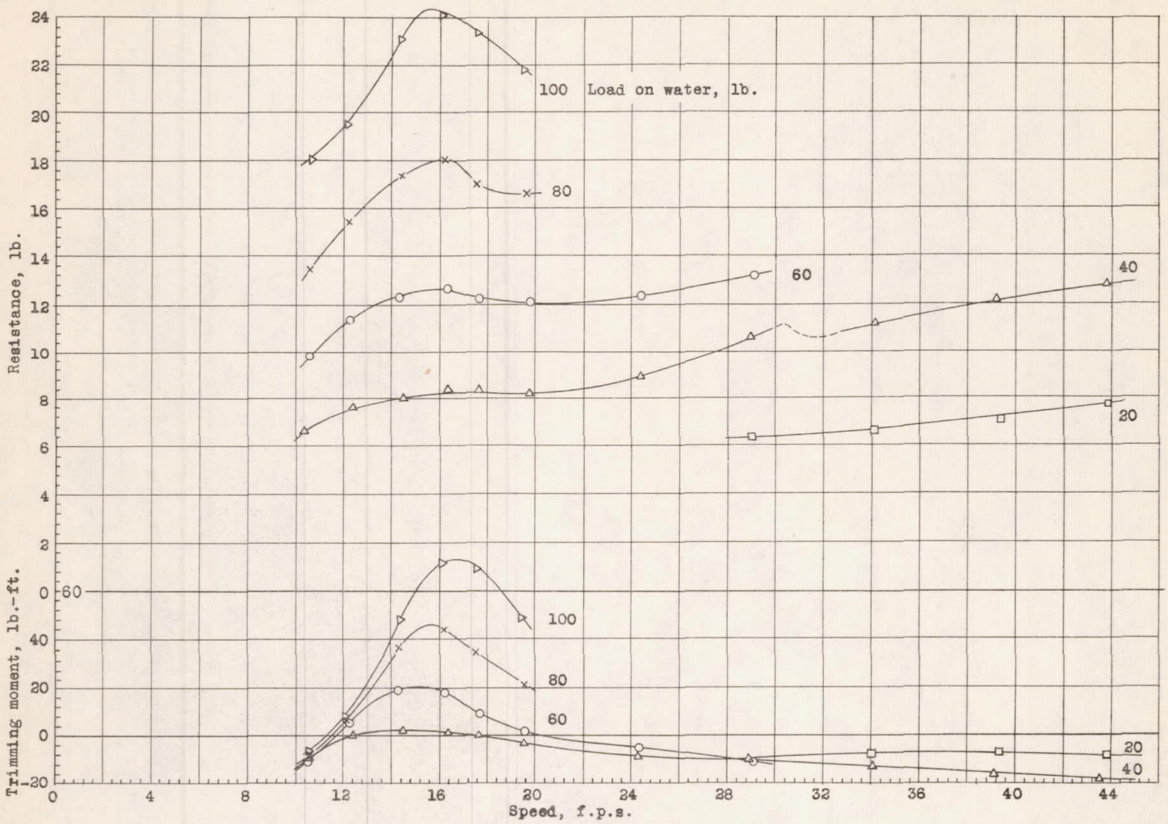


Figure 47.- Resistance and trimming moment, τ = 7°. Model 11-E-6

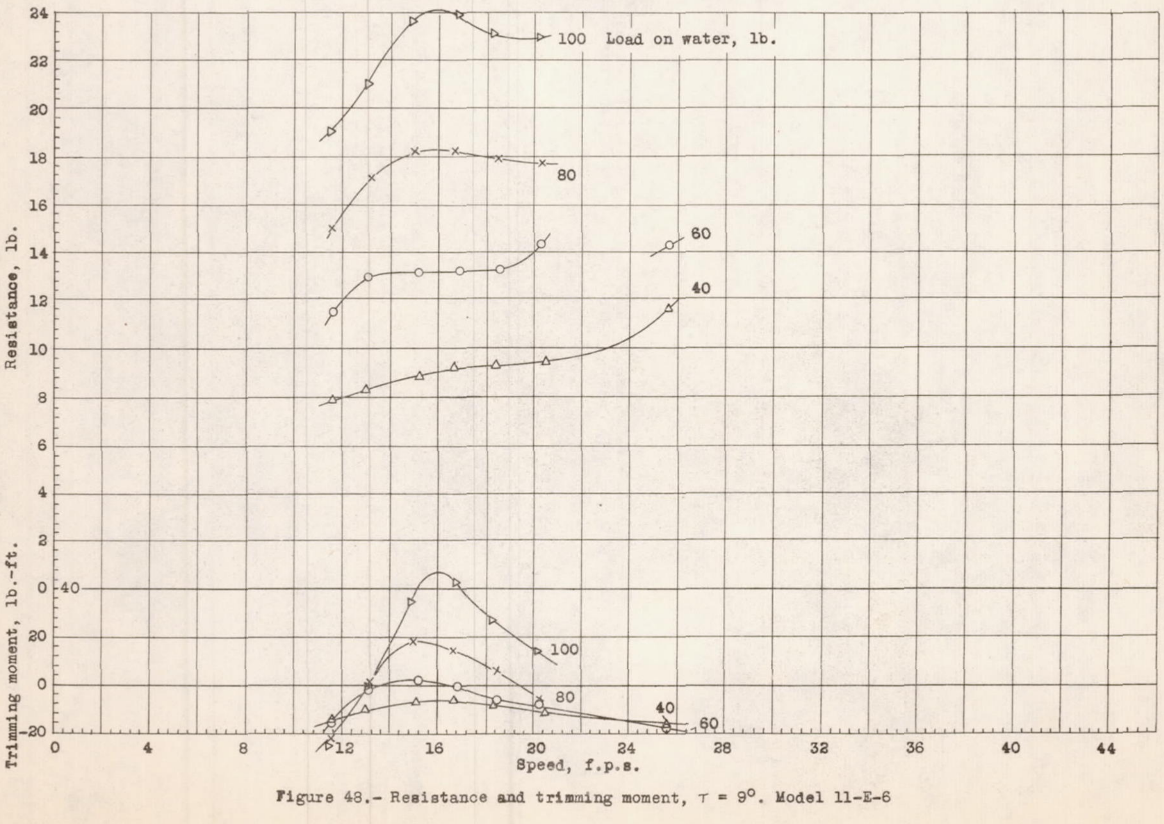


Figure 48.- Resistance and trimming moment, τ = 9°. Model 11-E-6

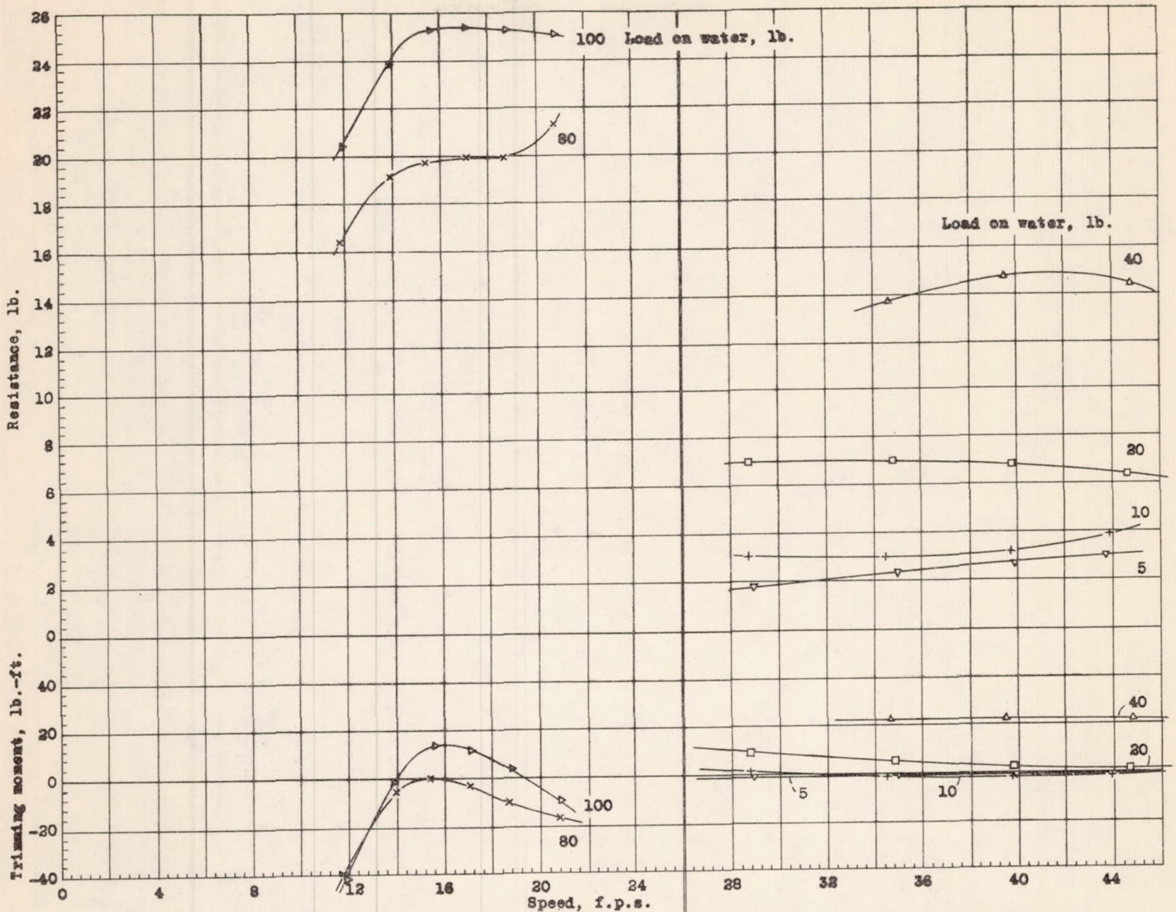


Figure 49.- Resistance and trimming moment, $\tau = 1\frac{1}{2}^{\circ}$. Model 11-E-6.

Figure 50.- Resistance and trimming moment, $\tau = 2^{\circ}$. Model 11-E-7.

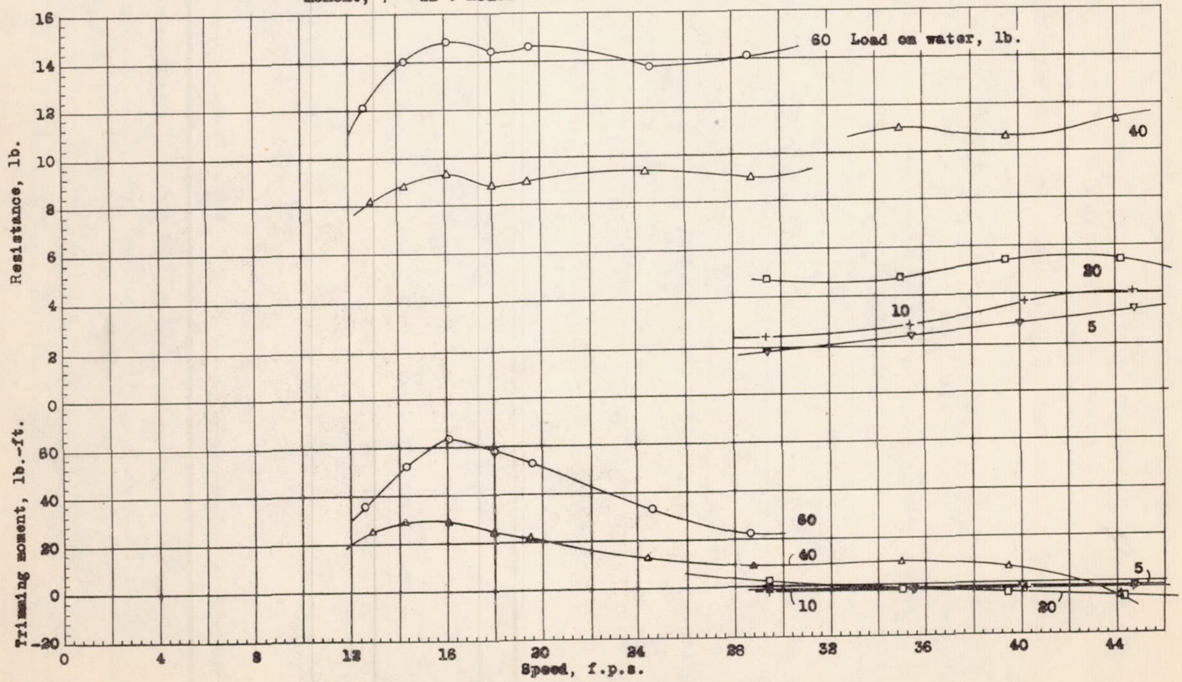


Figure 51.- Resistance and trimming moment, $\tau = 3^{\circ}$. Model 11-E-7.

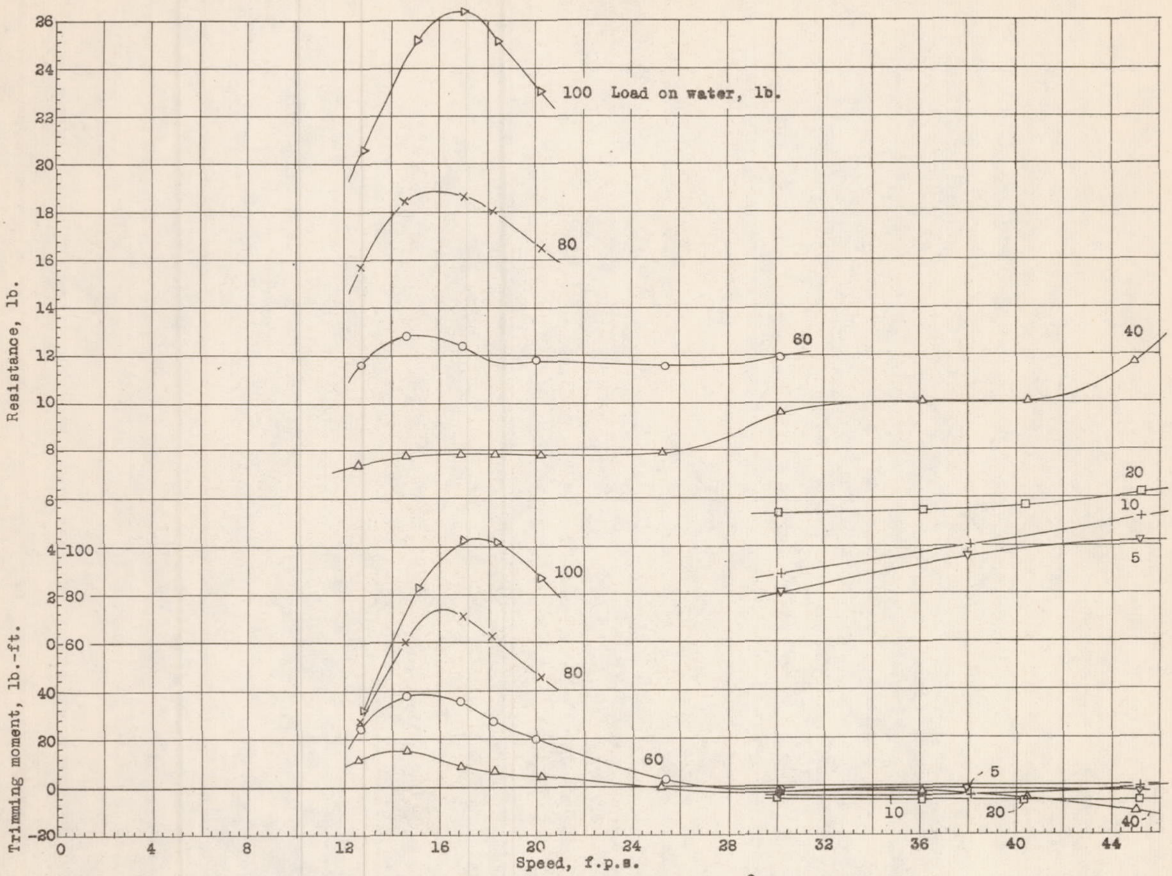


Figure 52.- Resistance and trimming moment, τ = 5°. Model 11-E-7.

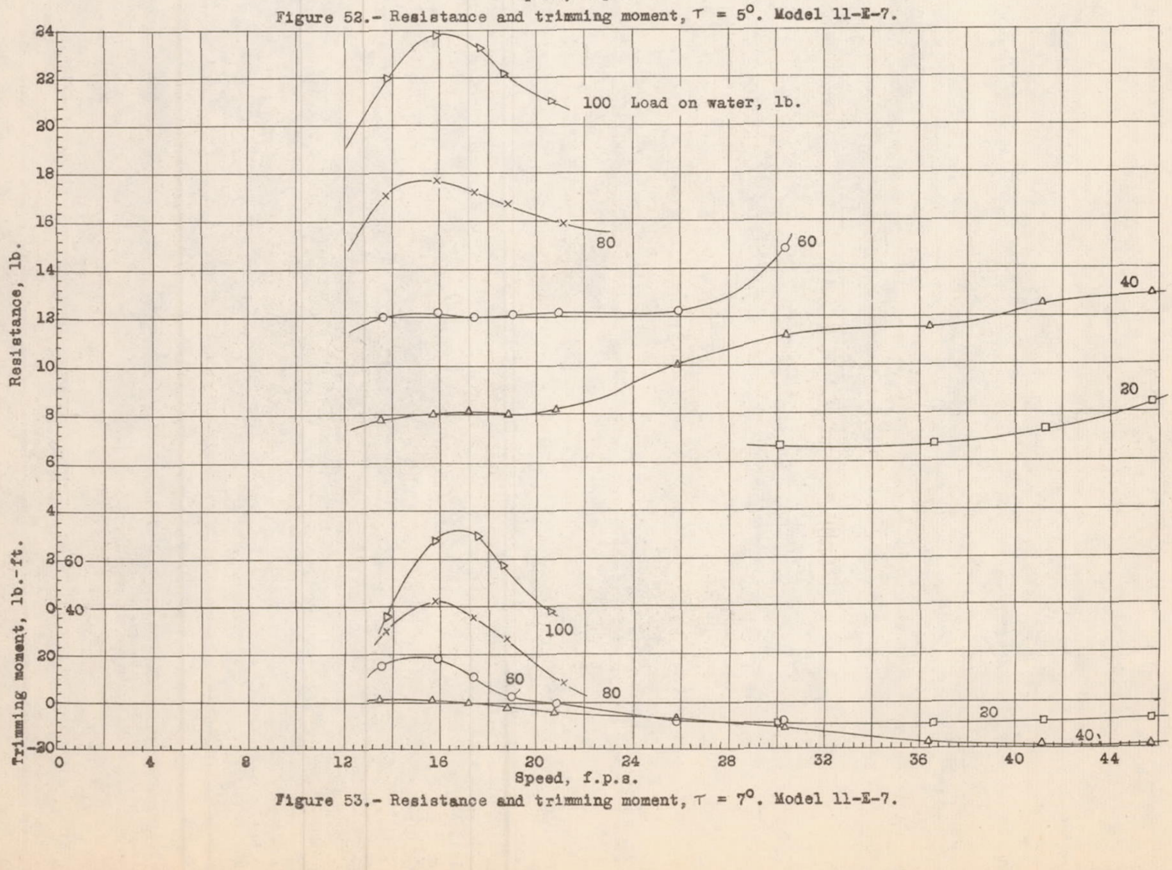


Figure 53.- Resistance and trimming moment, τ = 7°. Model 11-E-7.

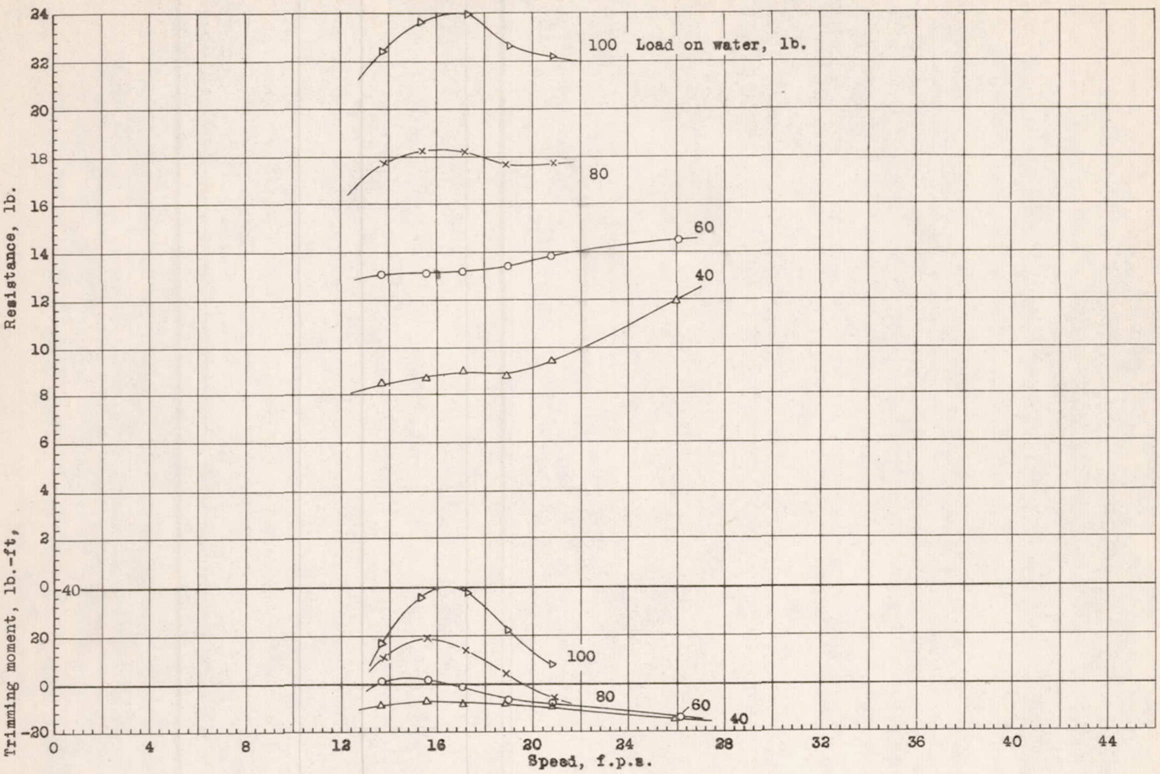


Figure 54.- Resistance and trimming moment, τ = 9°. Model 11-E-7.

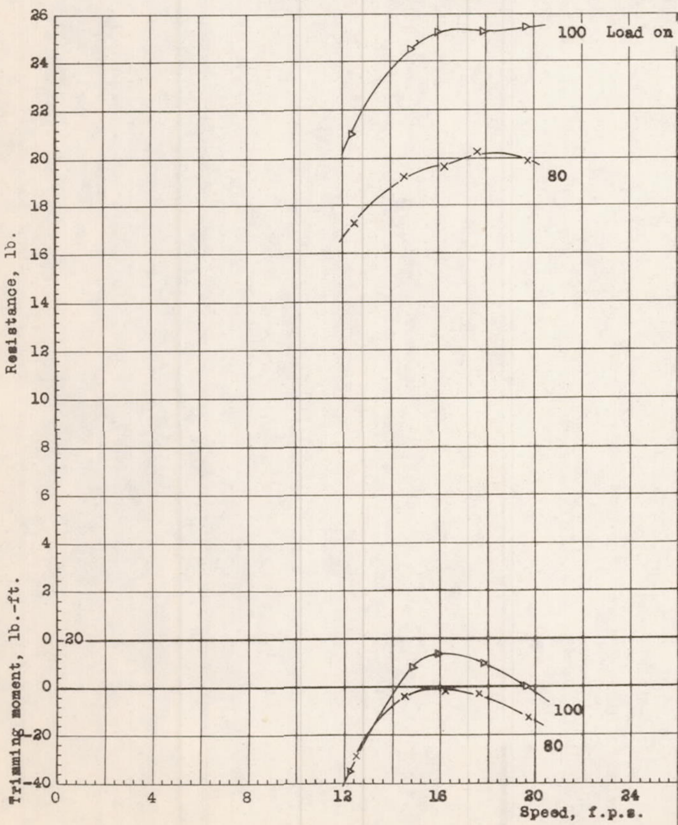


Figure 55.- Resistance and trimming moment, τ = 11°. Model 11-E-7.

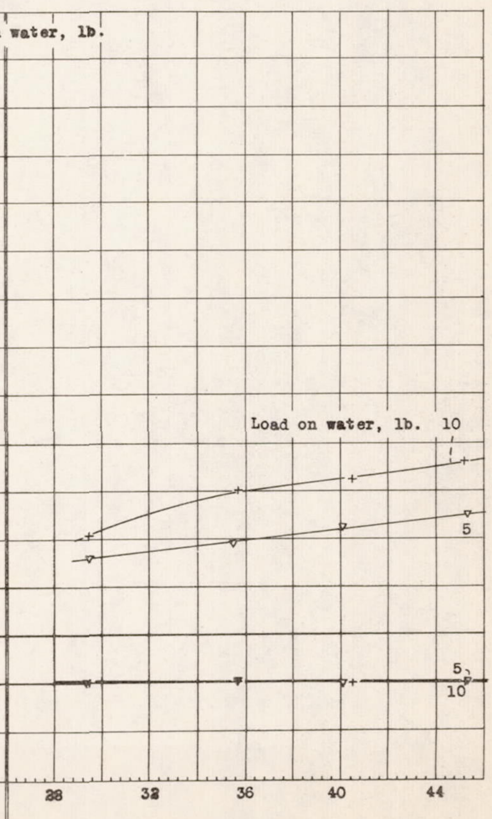


Figure 56.- Resistance and trimming moment, τ = 2°. Model 11-F.

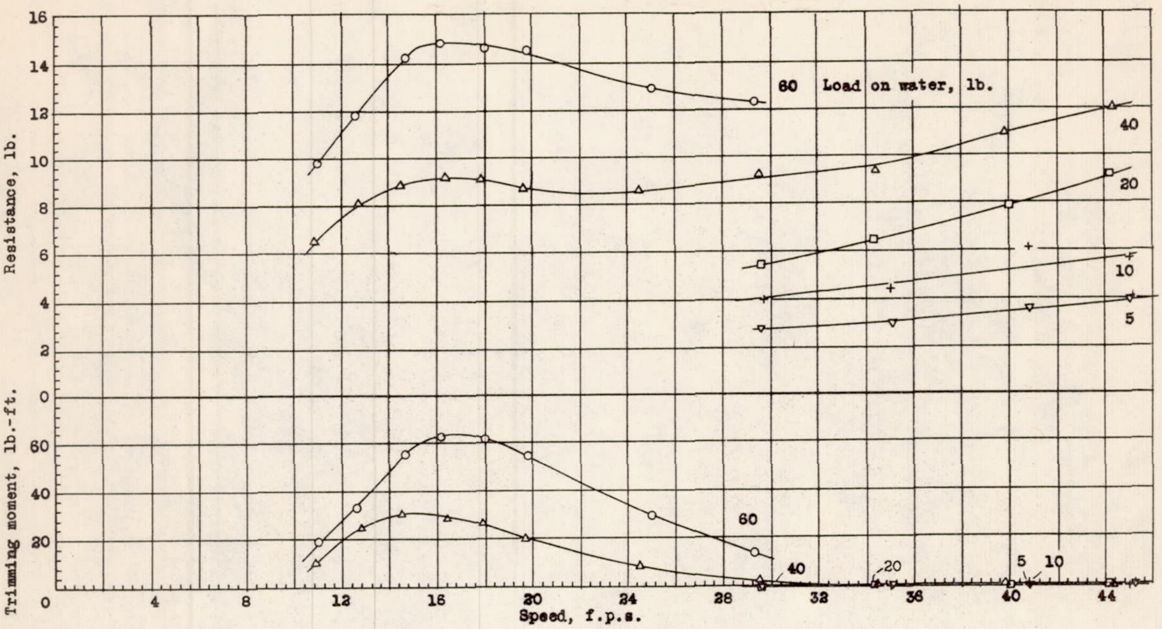


Figure 57.- Resistance and trimming moment, $\tau = 3^{\circ}$. Model 11-F

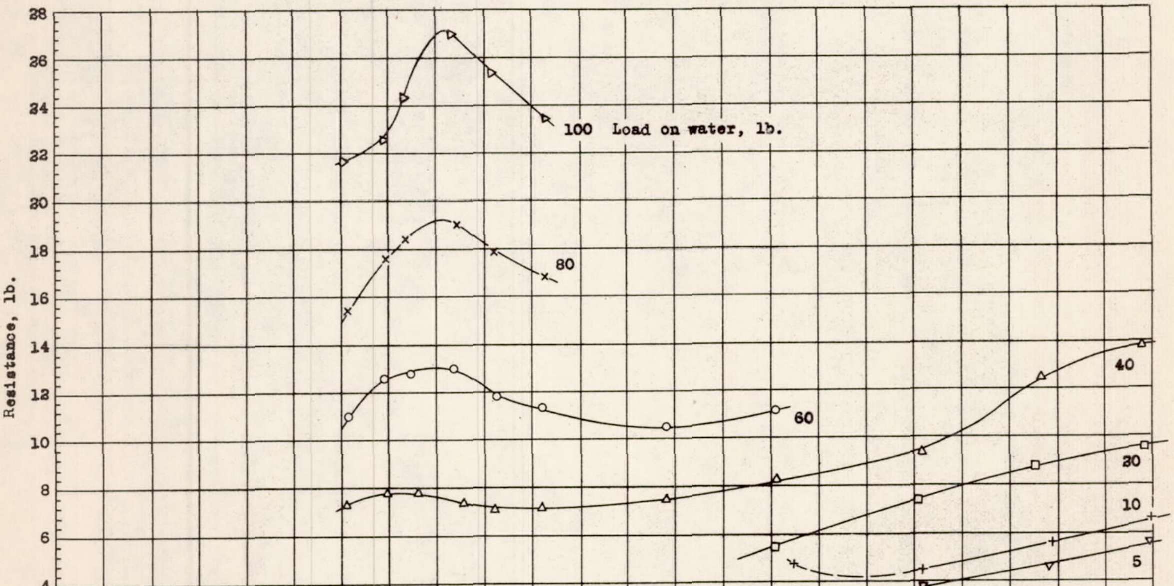


Figure 58.- Resistance and trimming moment, $\tau = 5^{\circ}$. Model 11-F.

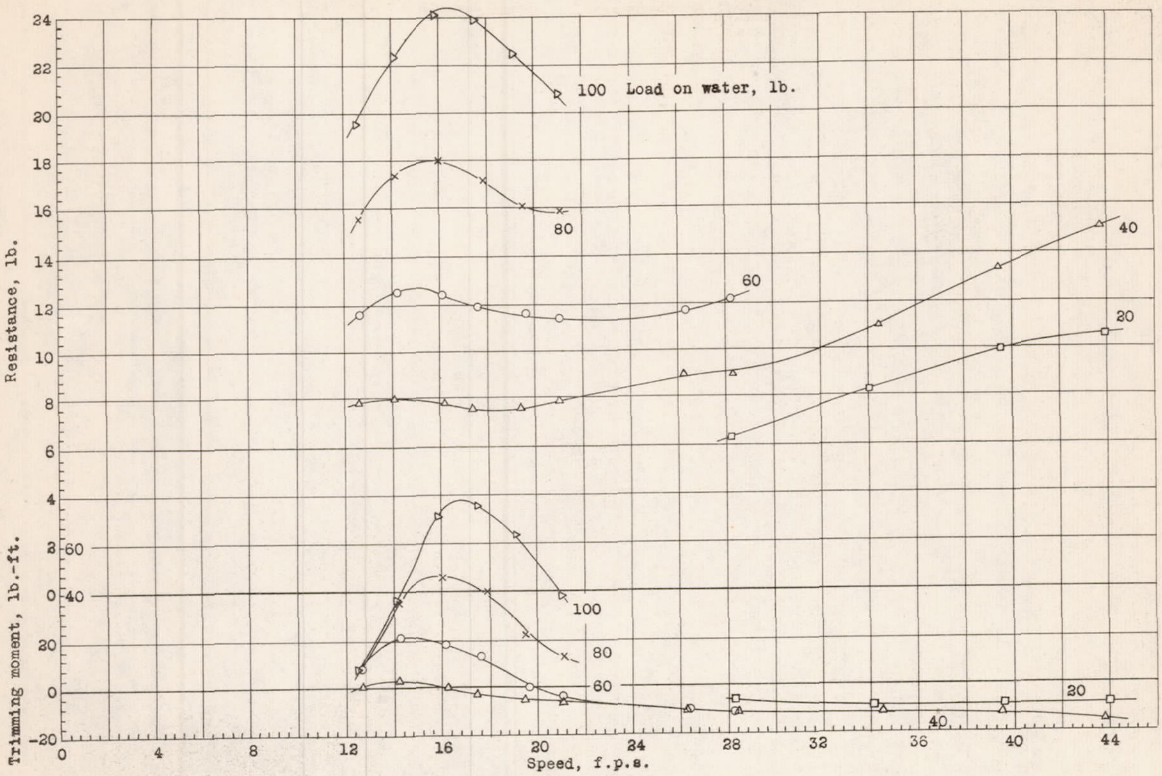


Figure 59.- Resistance and trimming moment, $\tau = 7^{\circ}$. Model 11-F.

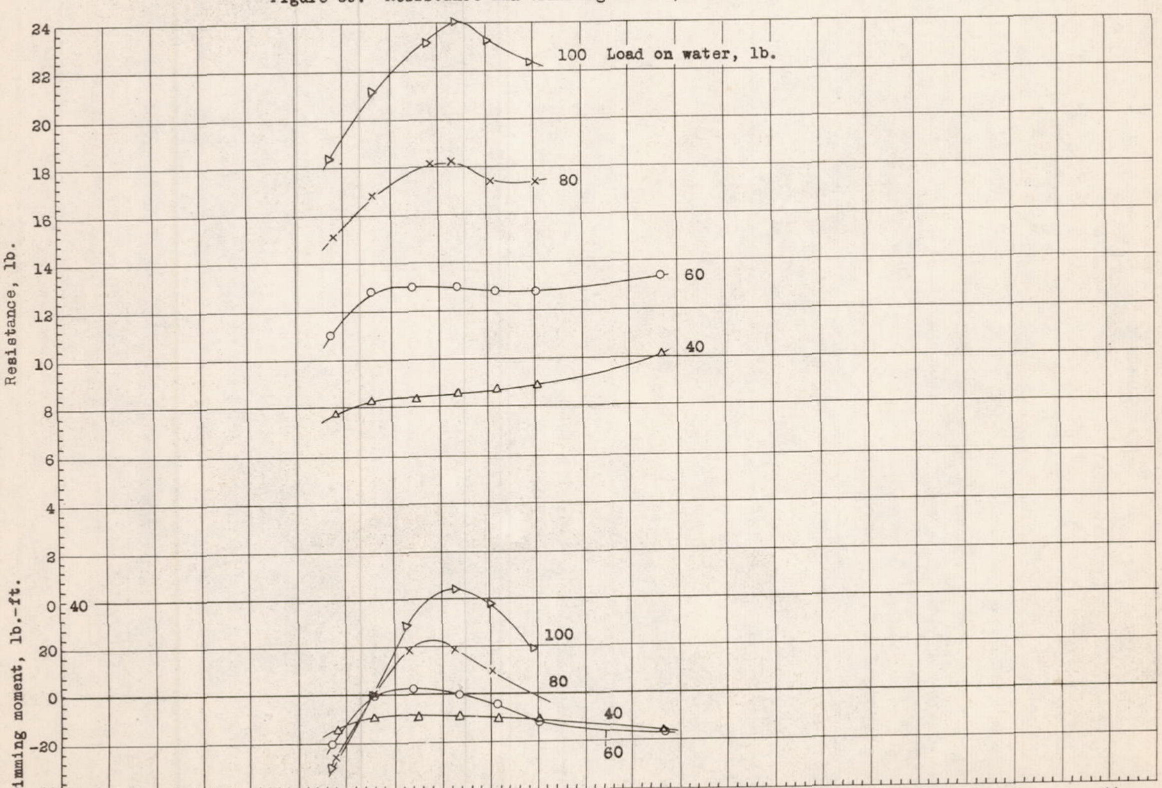


Figure 60.- Resistance and trimming moment, $\tau = 9^{\circ}$. Model 11-F.

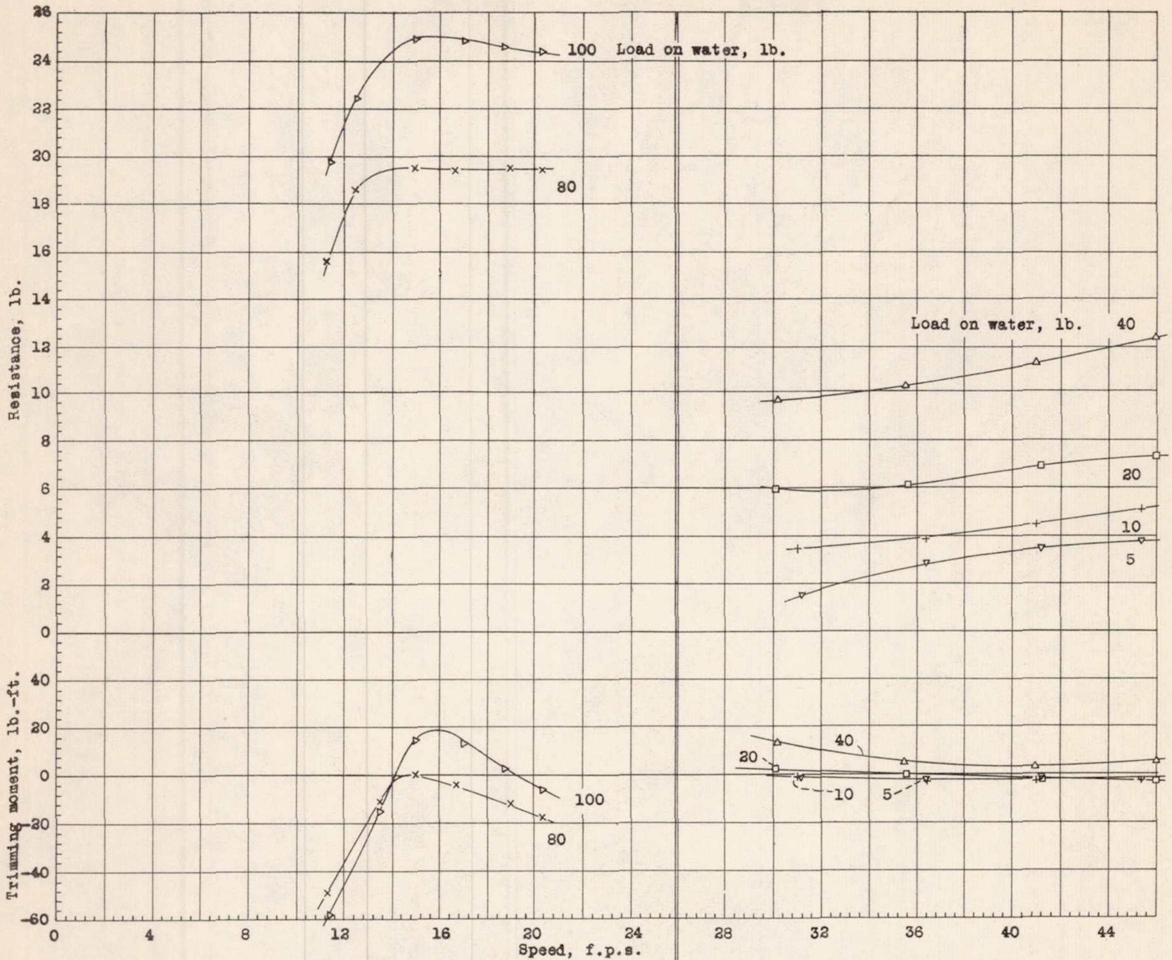


Figure 61.- Resistance and trimming moment, $\tau = 11^{\circ}$. Model 11-F.

Figure 62.- Resistance and trimming moment, $\tau = 2^{\circ}$. Model 11-F-1.

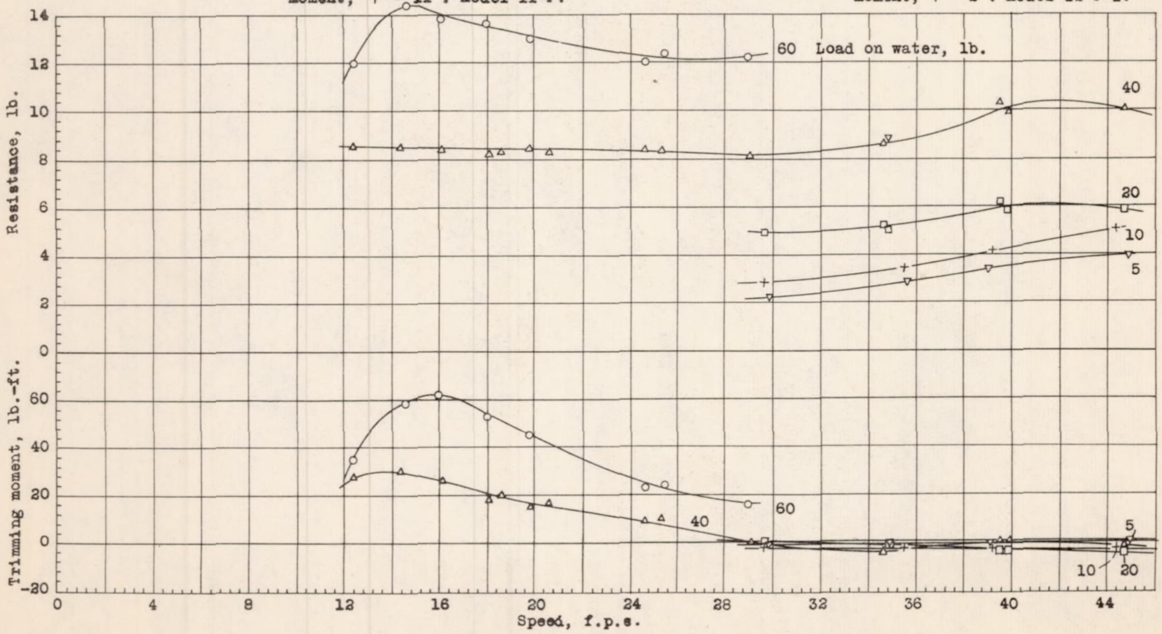


Figure 63.- Resistance and trimming moment, $\tau = 3^{\circ}$. Model 11-F-1.

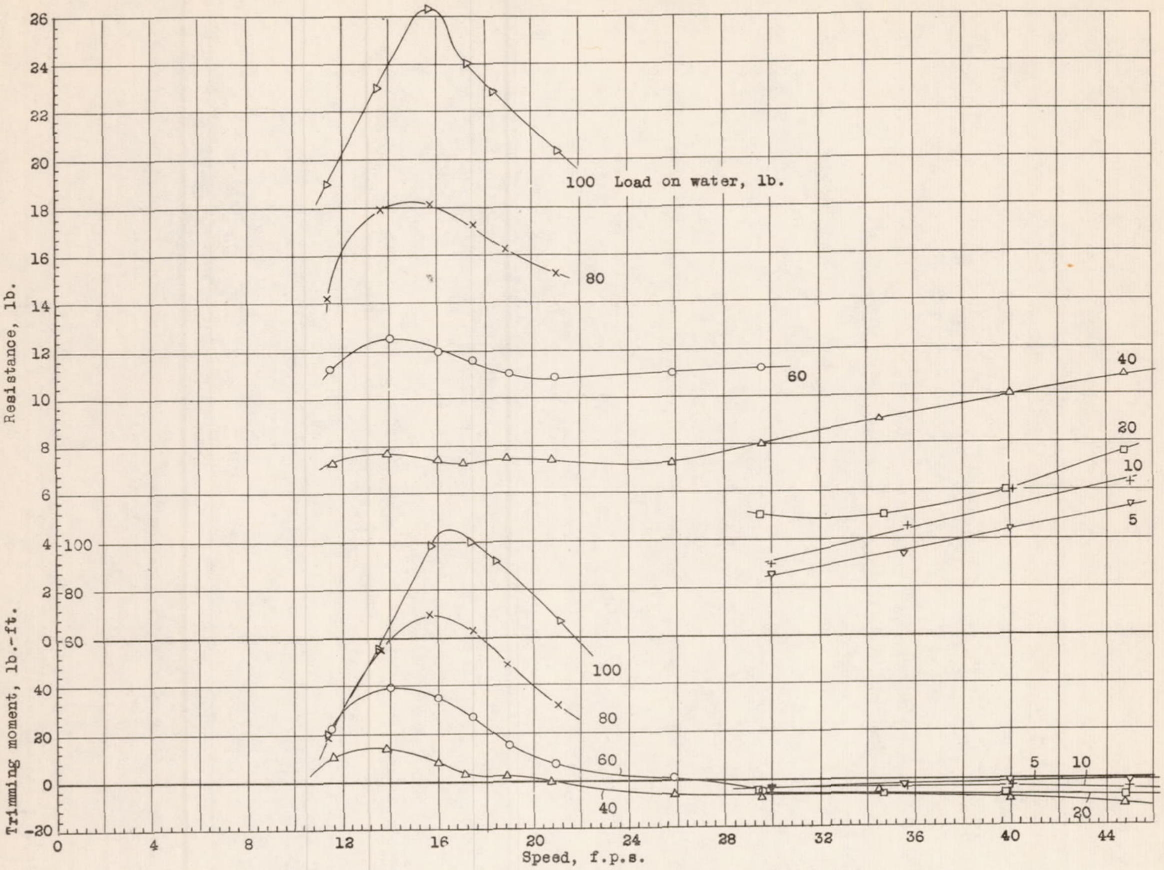


Figure 64.- Resistance and trimming moment, τ = 5°. Model 11-F-1.

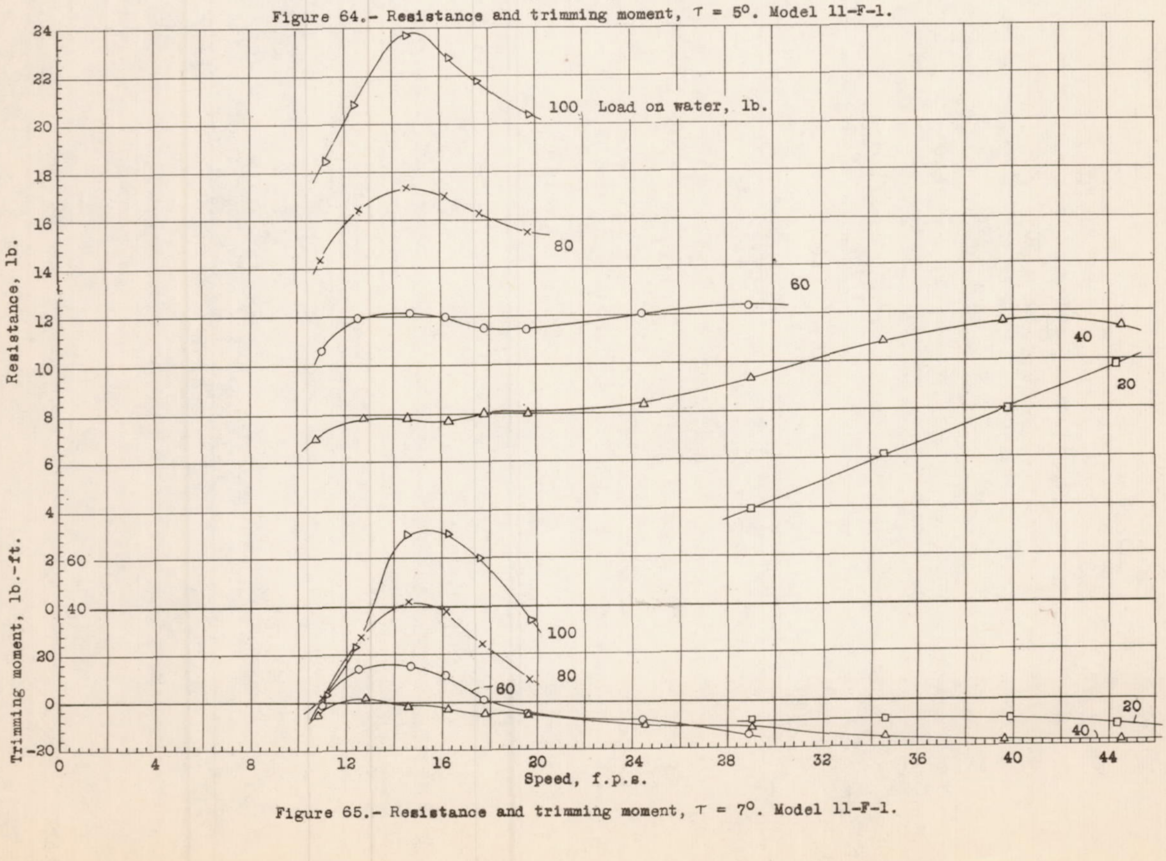


Figure 65.- Resistance and trimming moment, τ = 7°. Model 11-F-1.

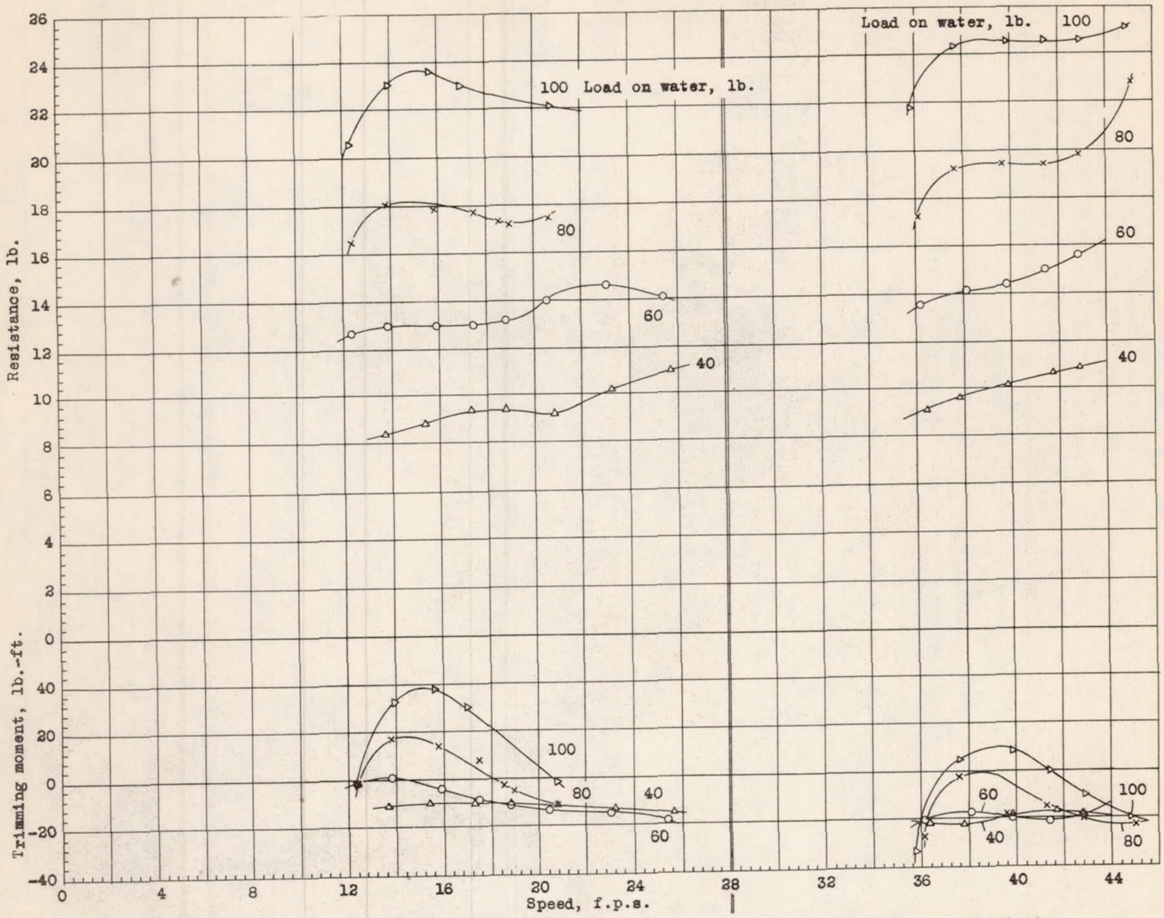


Figure 66.- Resistance and trimming moment, τ = 9°. Model 11-F-1.

Figure 67.- Resistance and trimming moment, τ = 11°. Model 11-F-1.

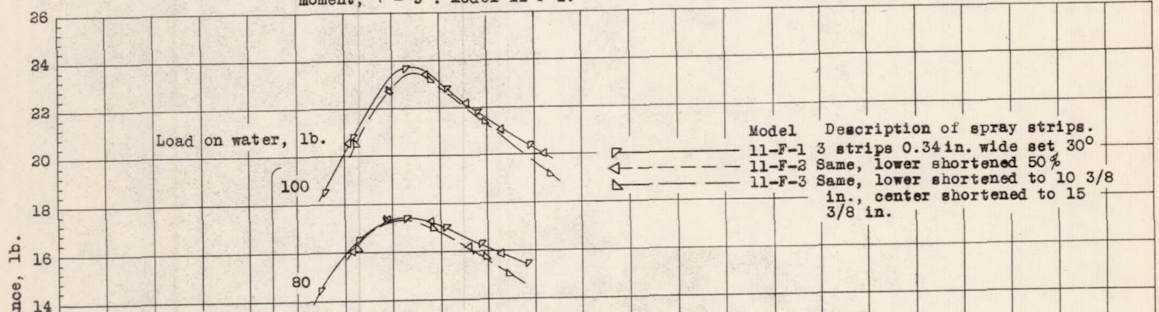


Figure 68.- Resistance comparison, Models 11-F-1, 11-F-2, 11-F-3 at τ = 7°, 5°, 3°.

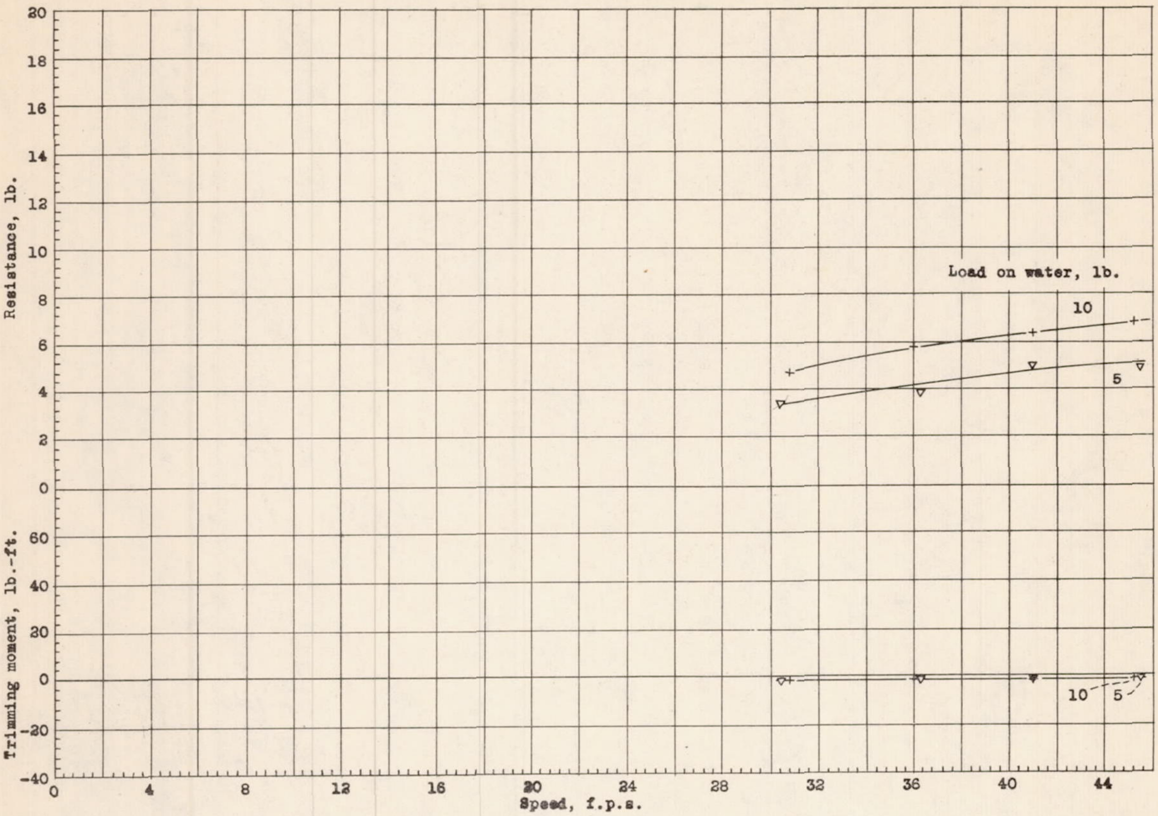


Figure 69.- Resistance and trimming moment, $\tau = 2^{\circ}$. Model 11-M.

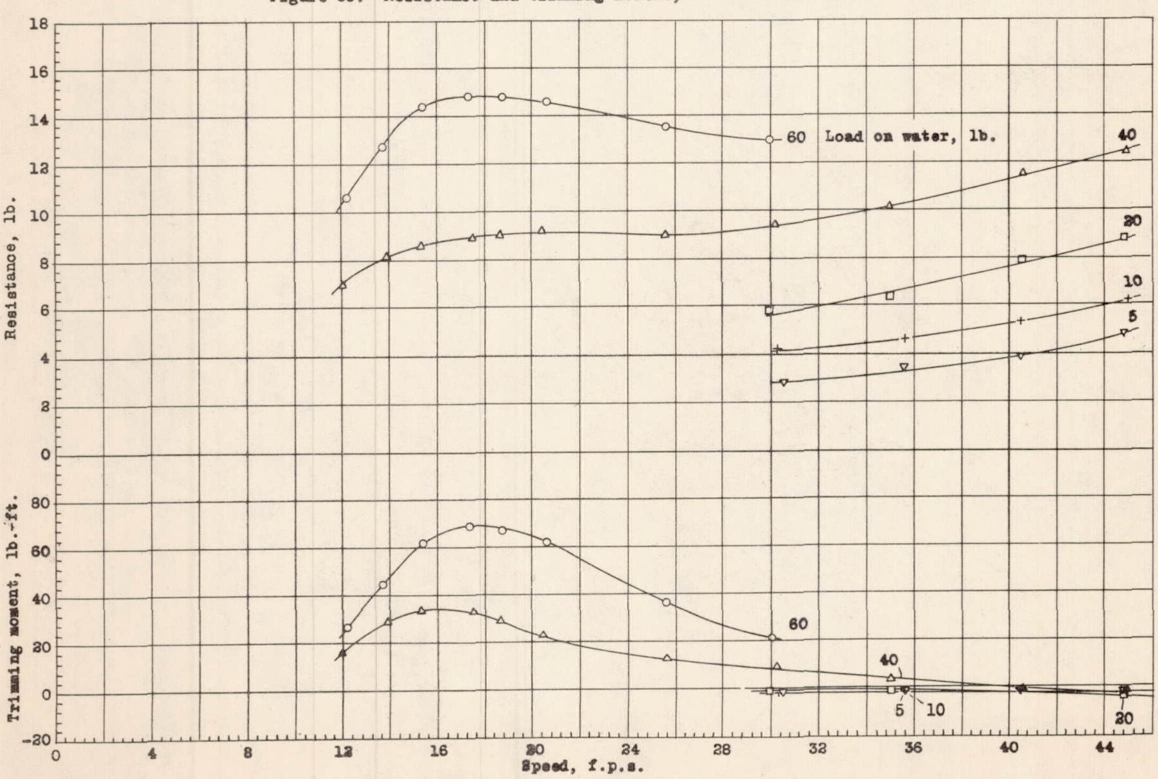


Figure 70.- Resistance and trimming moment, $\tau = 3^{\circ}$. Model 11-M.

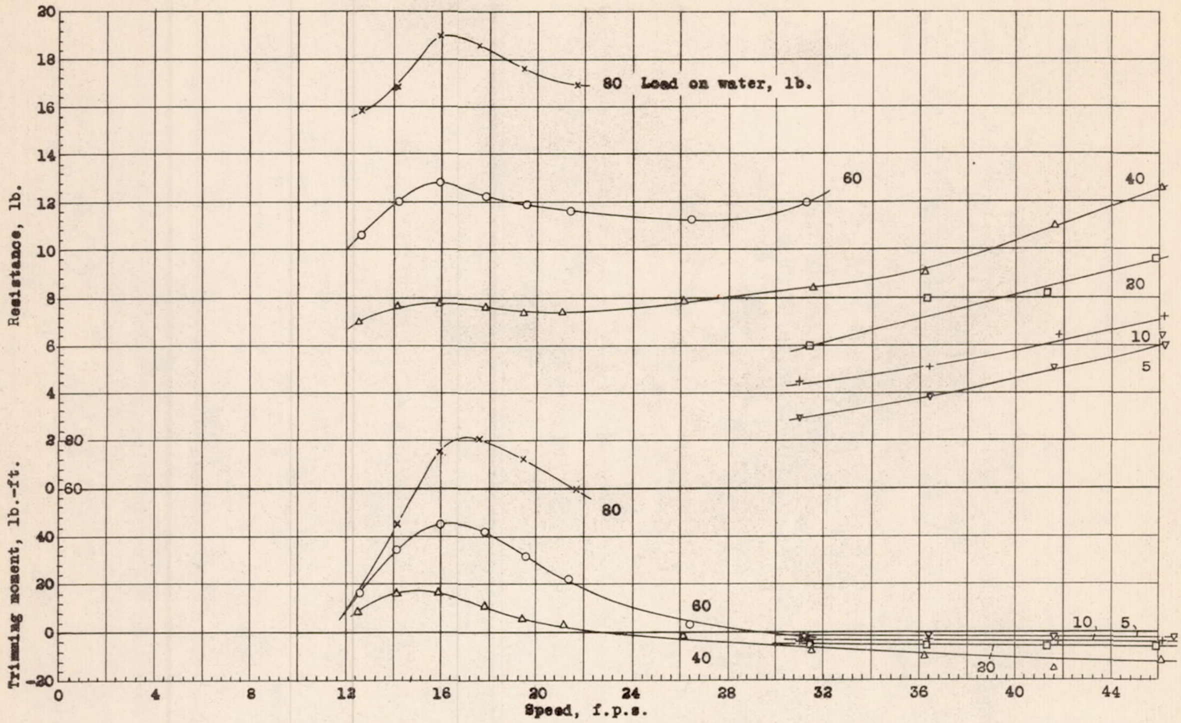


Figure 71.- Resistance and trimming moment, τ = 5°. Model 11-M.

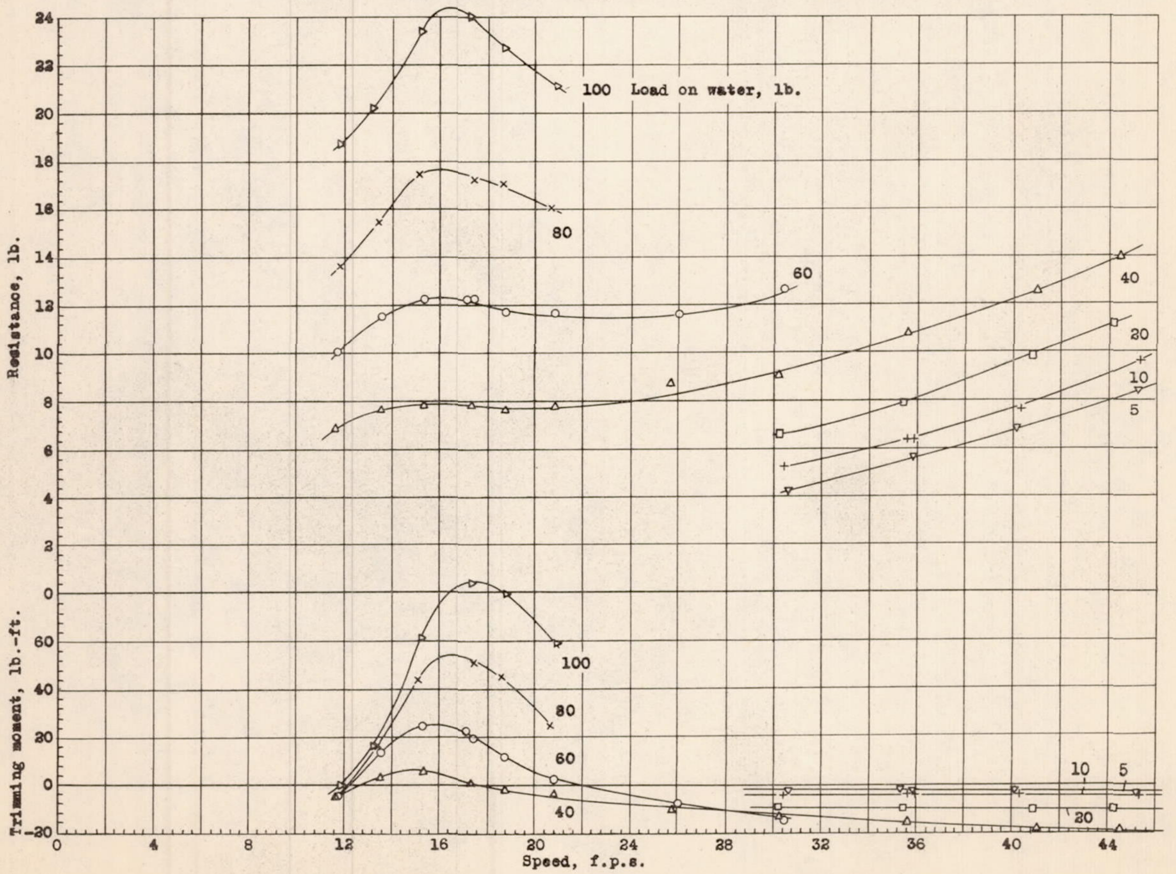


Figure 72.- Resistance and trimming moment, τ = 7°. Model 11-M.

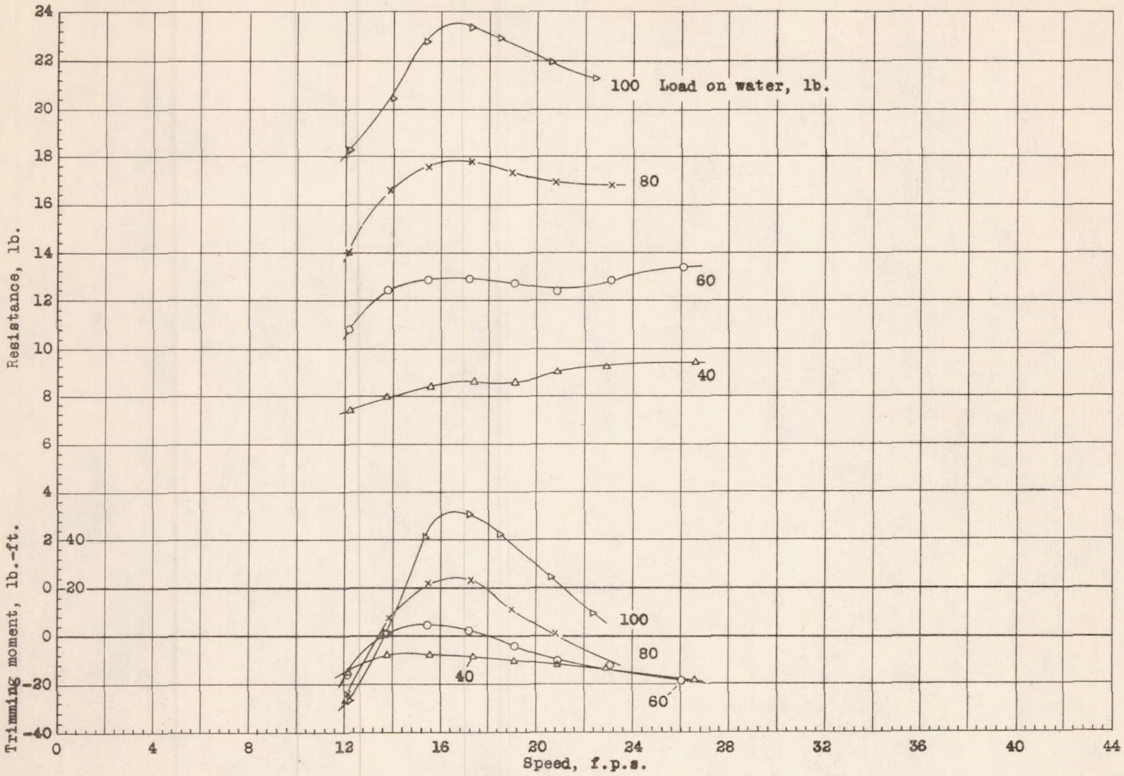


Figure 73.- Resistance and trimming moment, τ = 9°. Model 11-M.

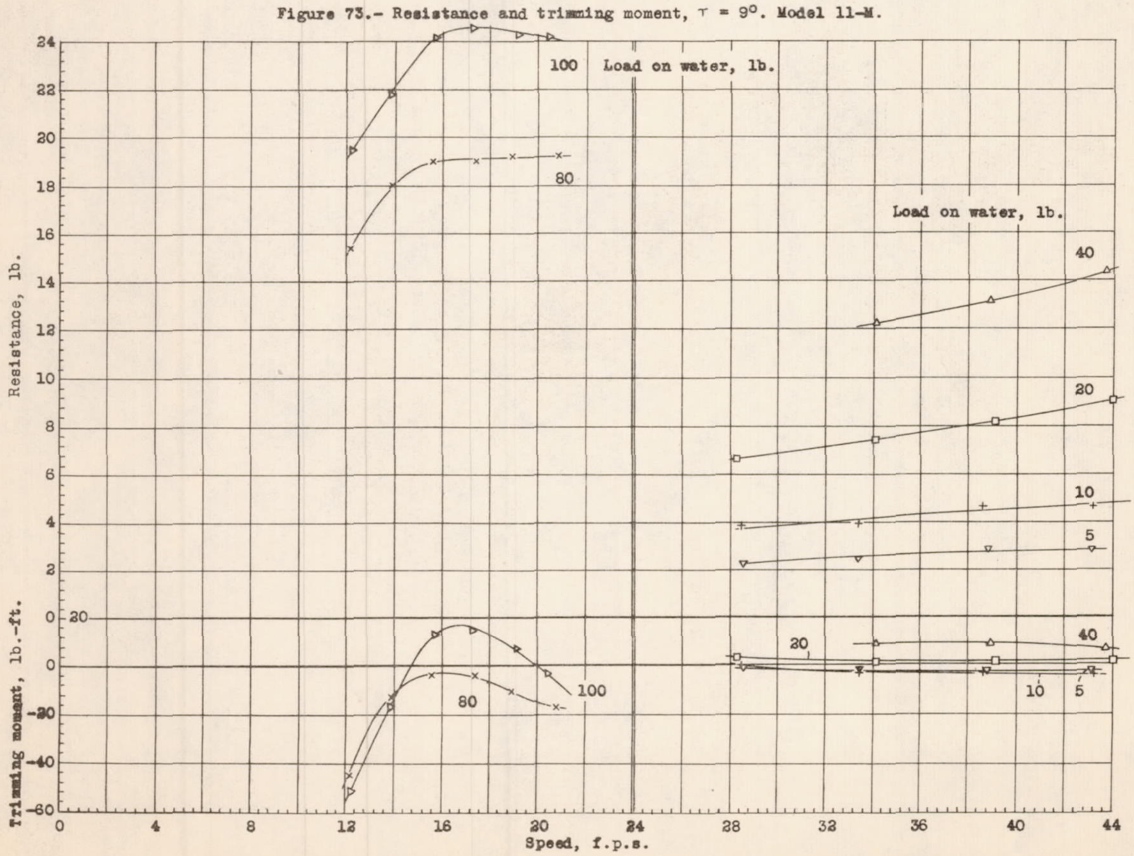


Figure 74.- Resistance and trimming moment, τ = 11°. Model 11-M

Figure 75.- Resistance and trimming moment, τ = 2°. Model 11-N.

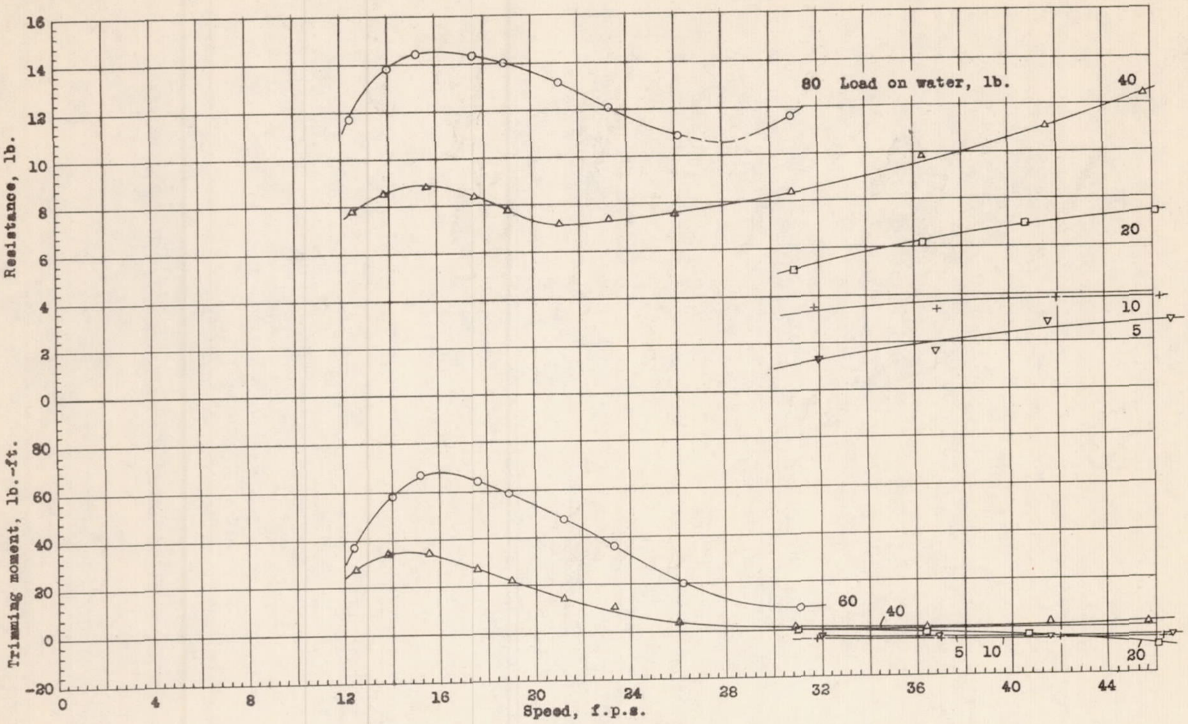


Figure 76.- Resistance and trimming moment, τ = 3°. Model 11-N.

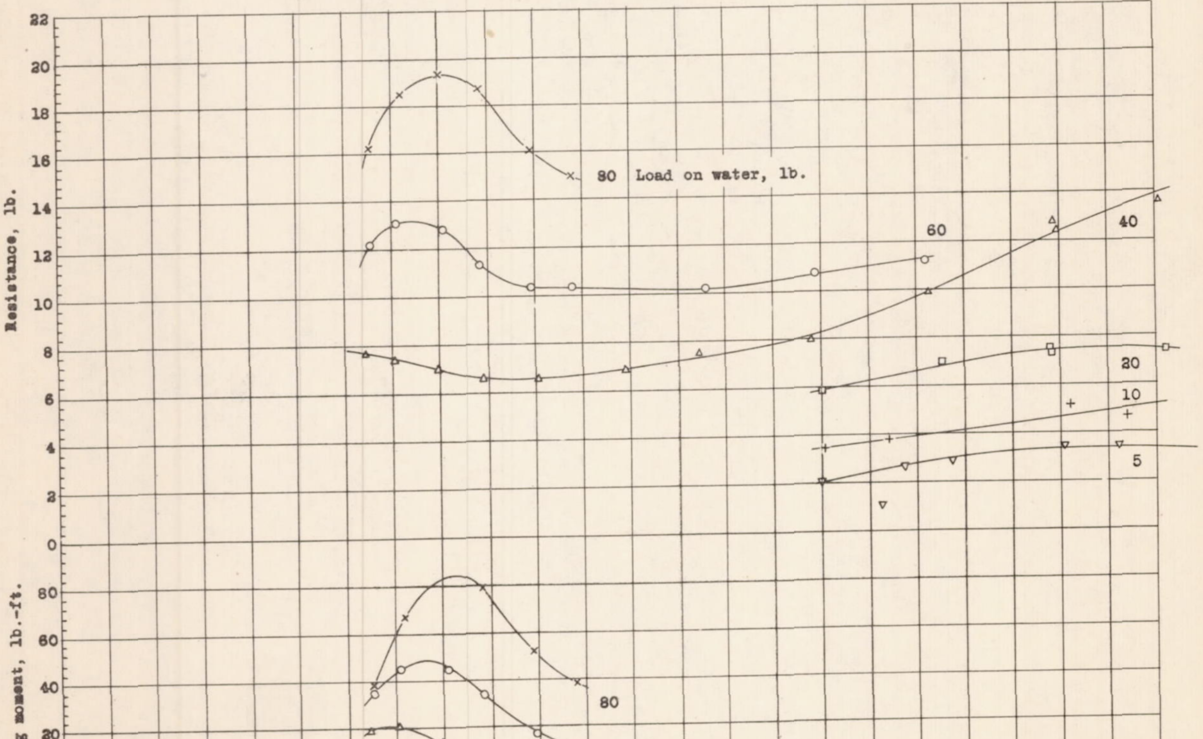


Figure 77.- Resistance and trimming moment, τ = 5°. Model 11-N.

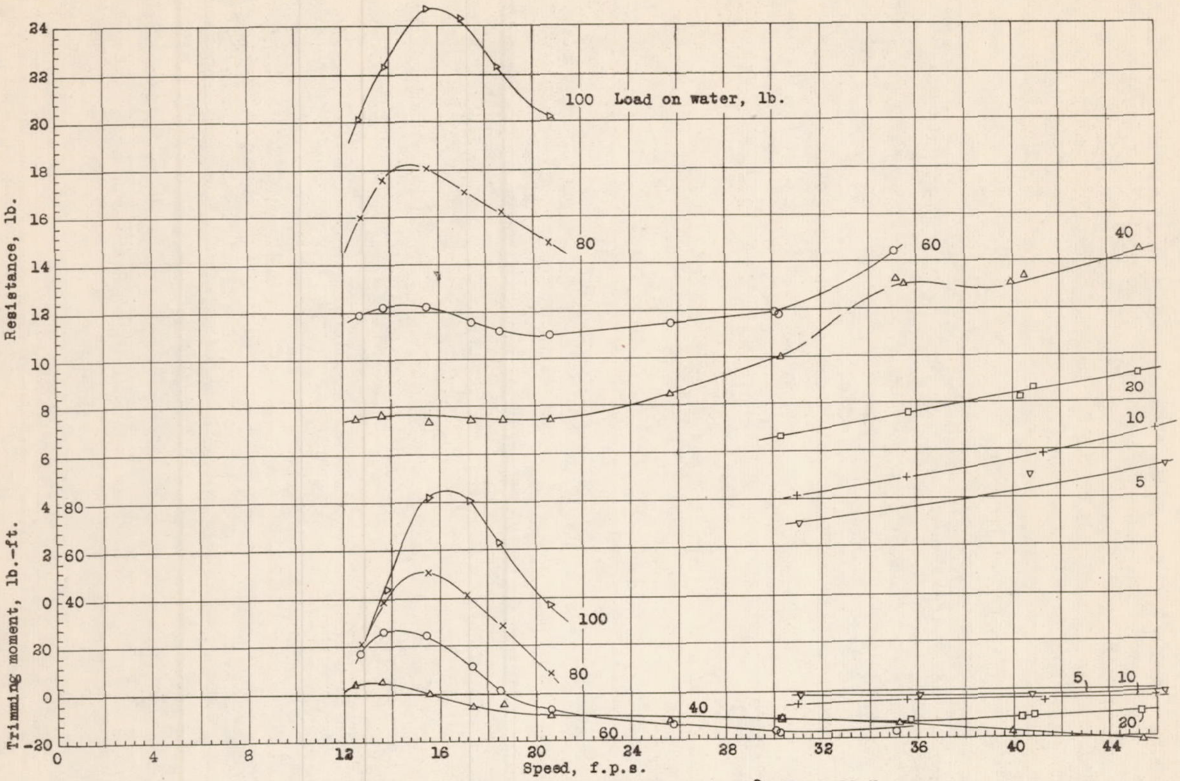
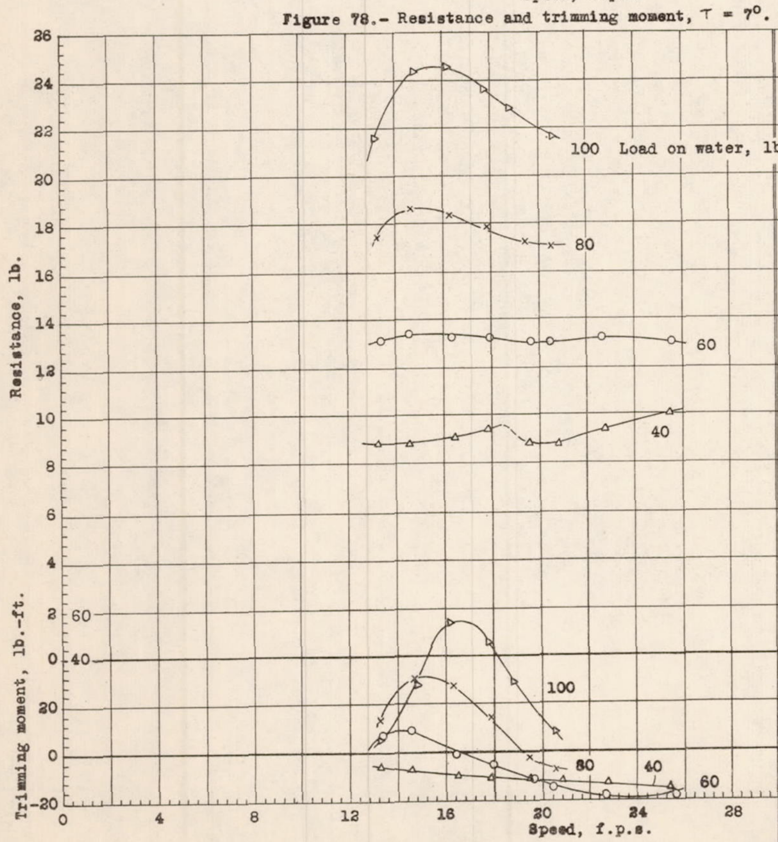


Figure 78.- Resistance and trimming moment, τ = 7°. Model 11-N.



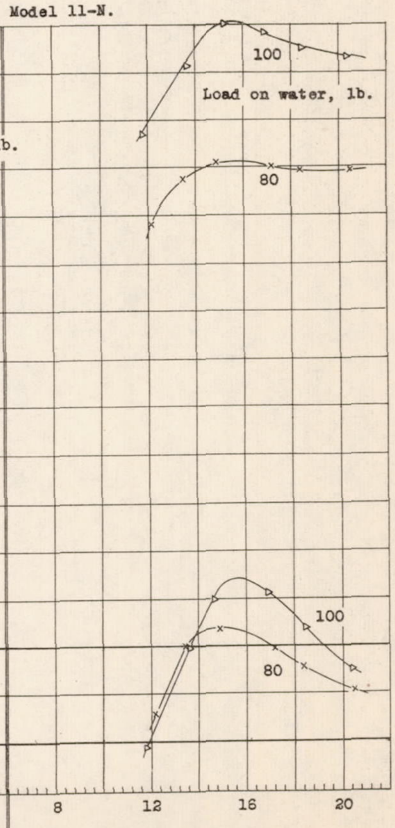


Figure 79.- Resistance and trimming moment, τ = 9°. Model 11-N.

Figure 80.- Resistance and trimming moment, τ = 11°. Model 11-N.

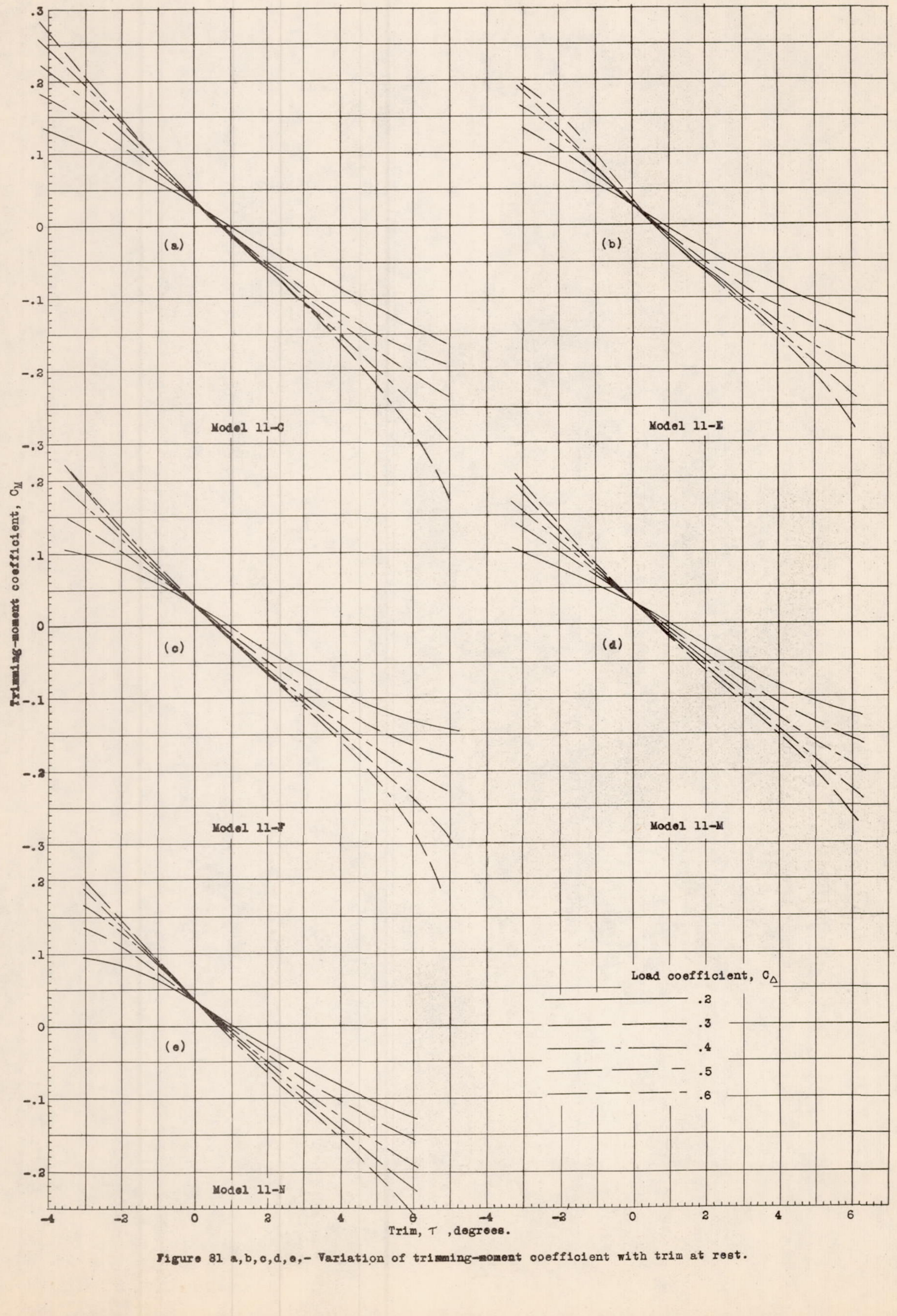


Figure 81 a,b,c,d,e,- Variation of trimming-moment coefficient with trim at rest.

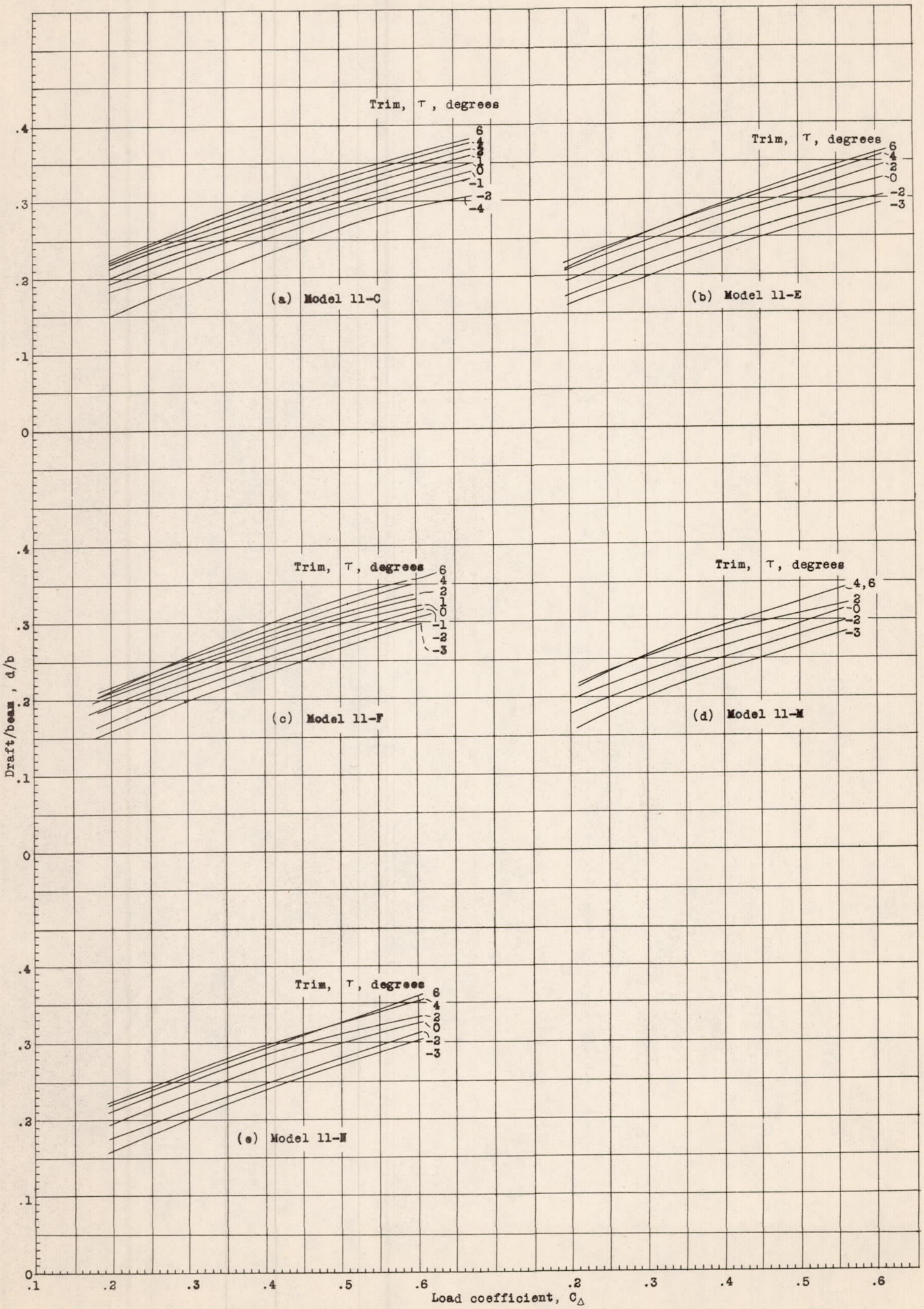


Figure 82(a to e). Variation of draft-beam ratio with C_Δ, at rest.

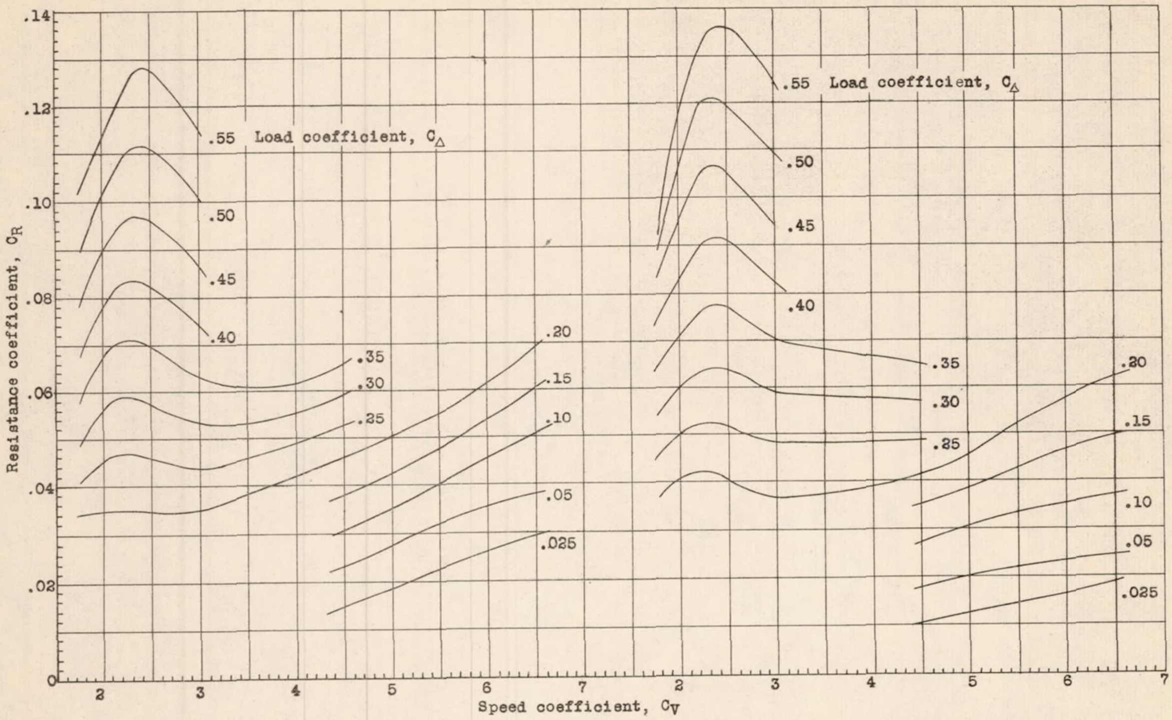


Figure 83.- Variation of C_R with C_V at best trim. Model 11-C.

Figure 84.- Variation of C_R with C_V at best trim. Model 11-E.

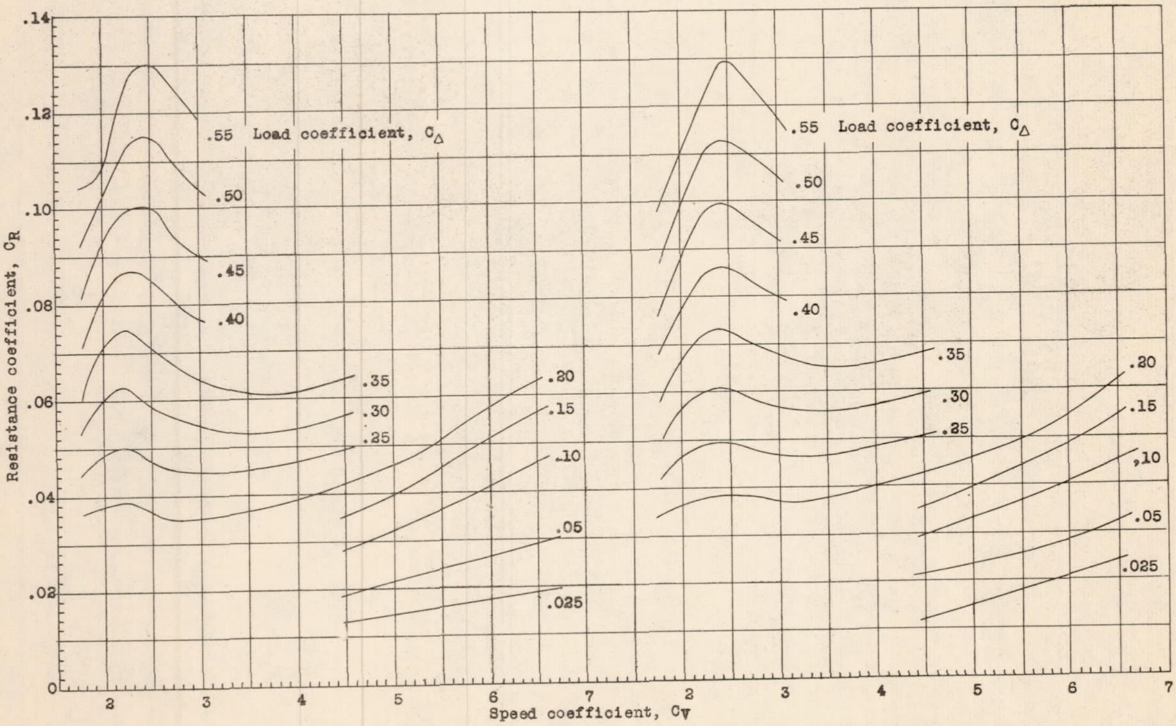


Figure 85.- Variation of C_R with C_V at best trim. Model 11-F.

Figure 87.- Variation of C_R with C_V at best trim. Model 11-M.

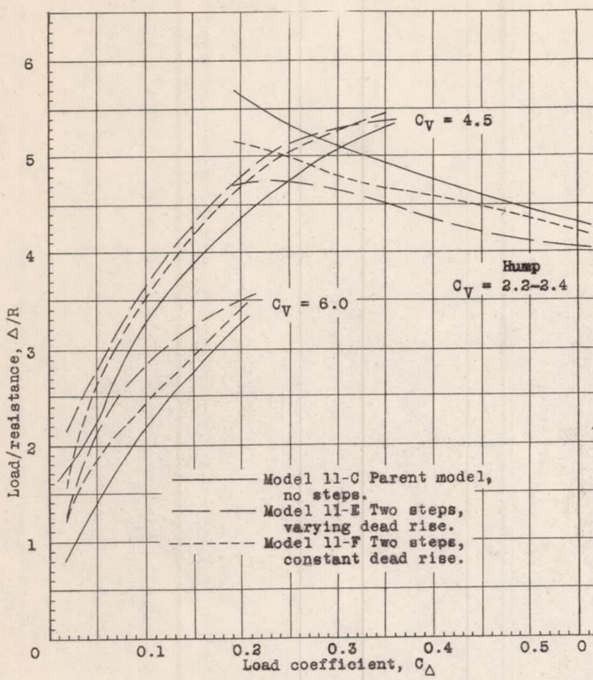


Figure 86.-Performance comparison of conventional model, 11-C, with longitudinal-step models, 11-E and 11-F.

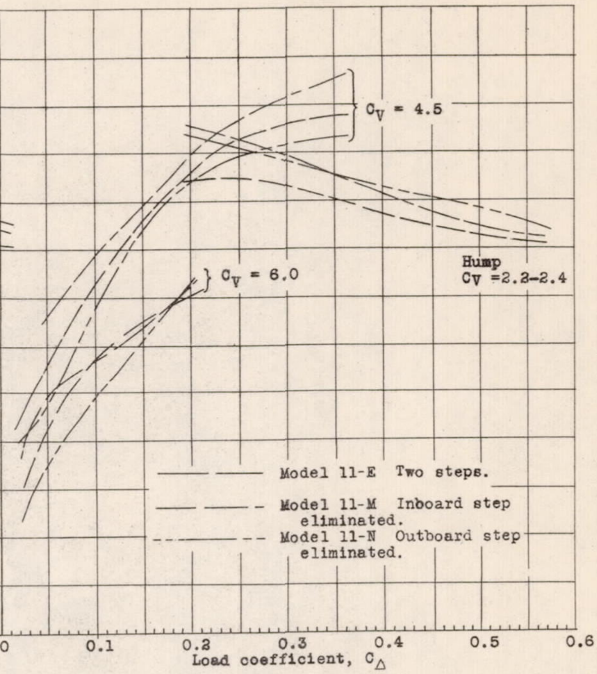


Figure 89.-The effect of eliminating one longitudinal step of a two-step model.

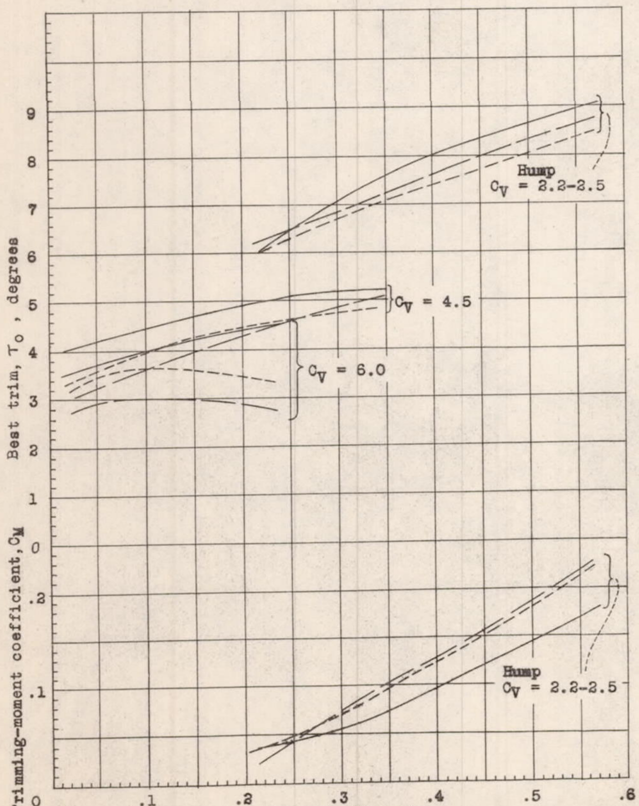


Figure 90.-The effect of longitudinal steps on best trim and trimming-moment coefficient at best trim.

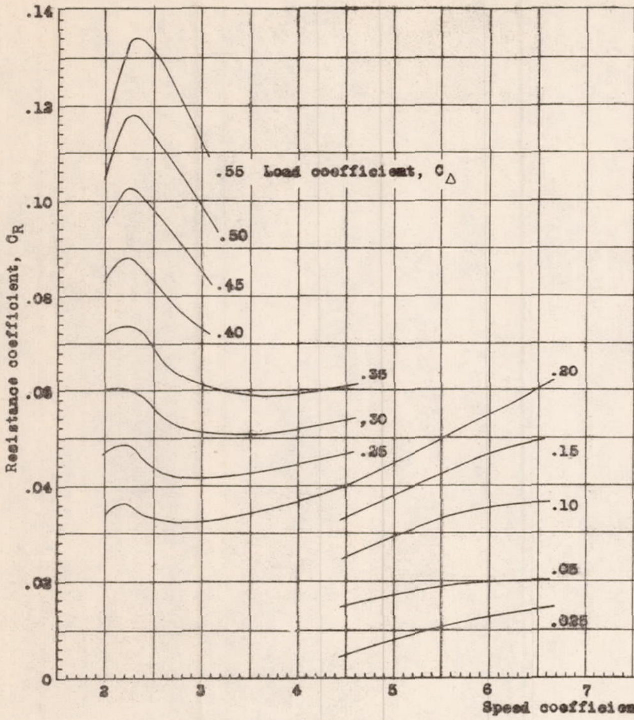


Figure 88.- Variation of C_R with C_V at best trim. Model 11-N.

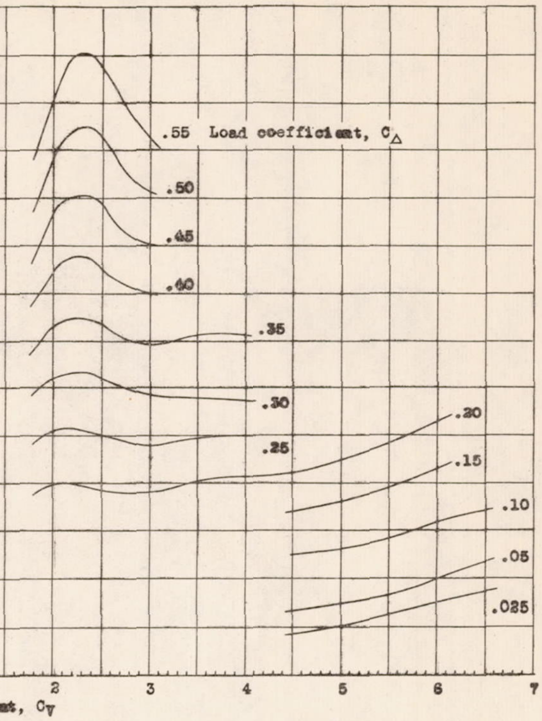


Figure 91.- Variation of C_R with C_V at best trim. Model 11-E-1.

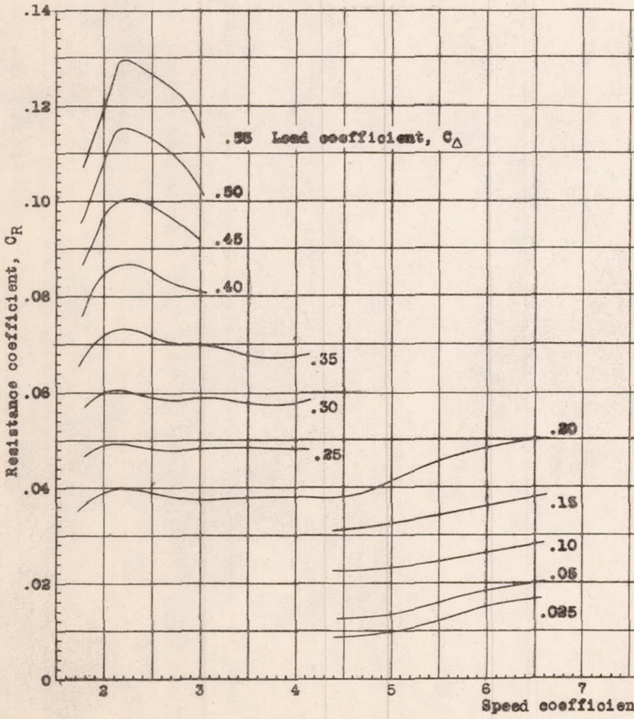


Figure 92.- Variation of C_R with C_V at best trim. Model 11-E-2.

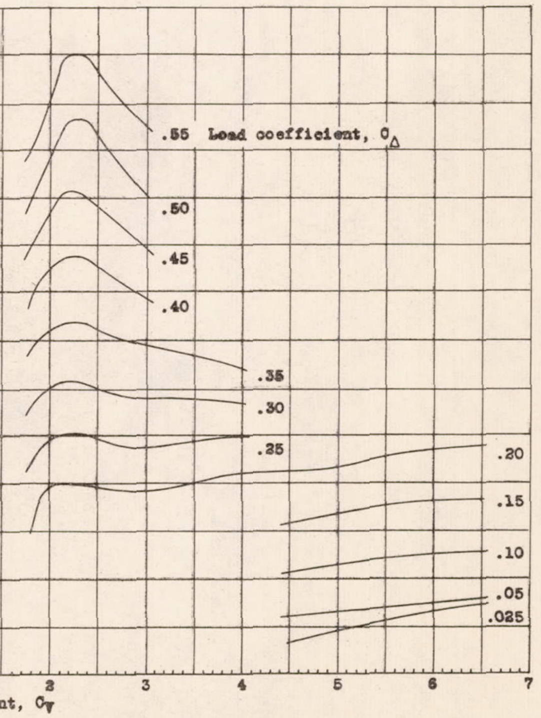


Figure 93.- Variation of C_R with C_V at best trim. Model 11-E-3.

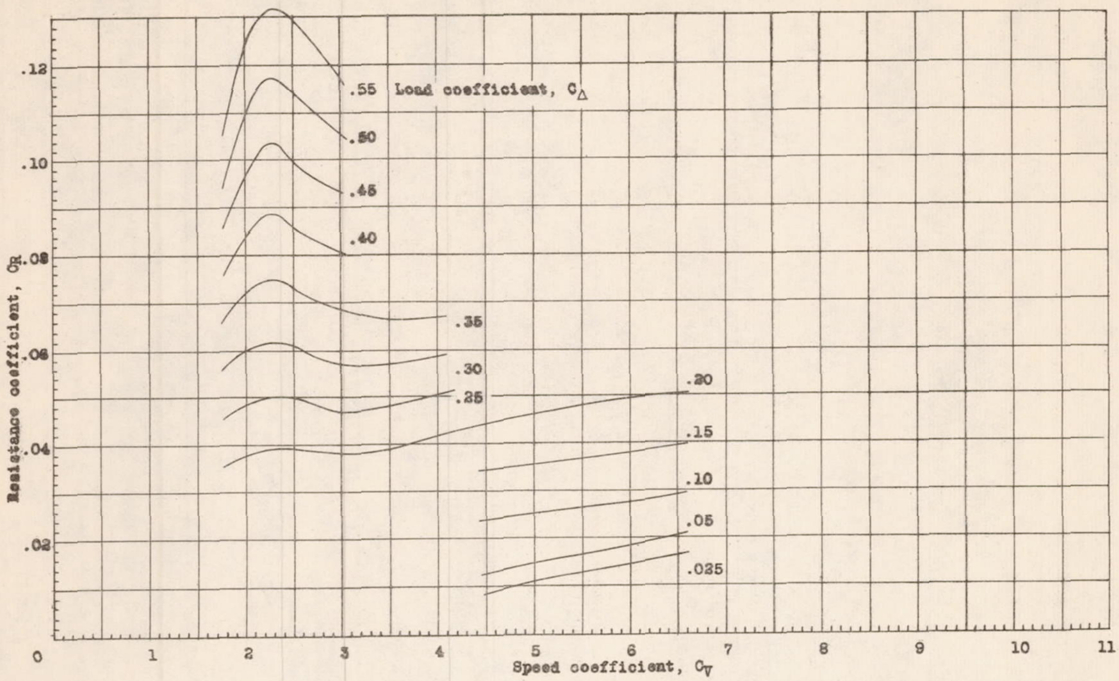


Figure 94.-Variation of C_R with C_V at best trim. Model 11-E-4

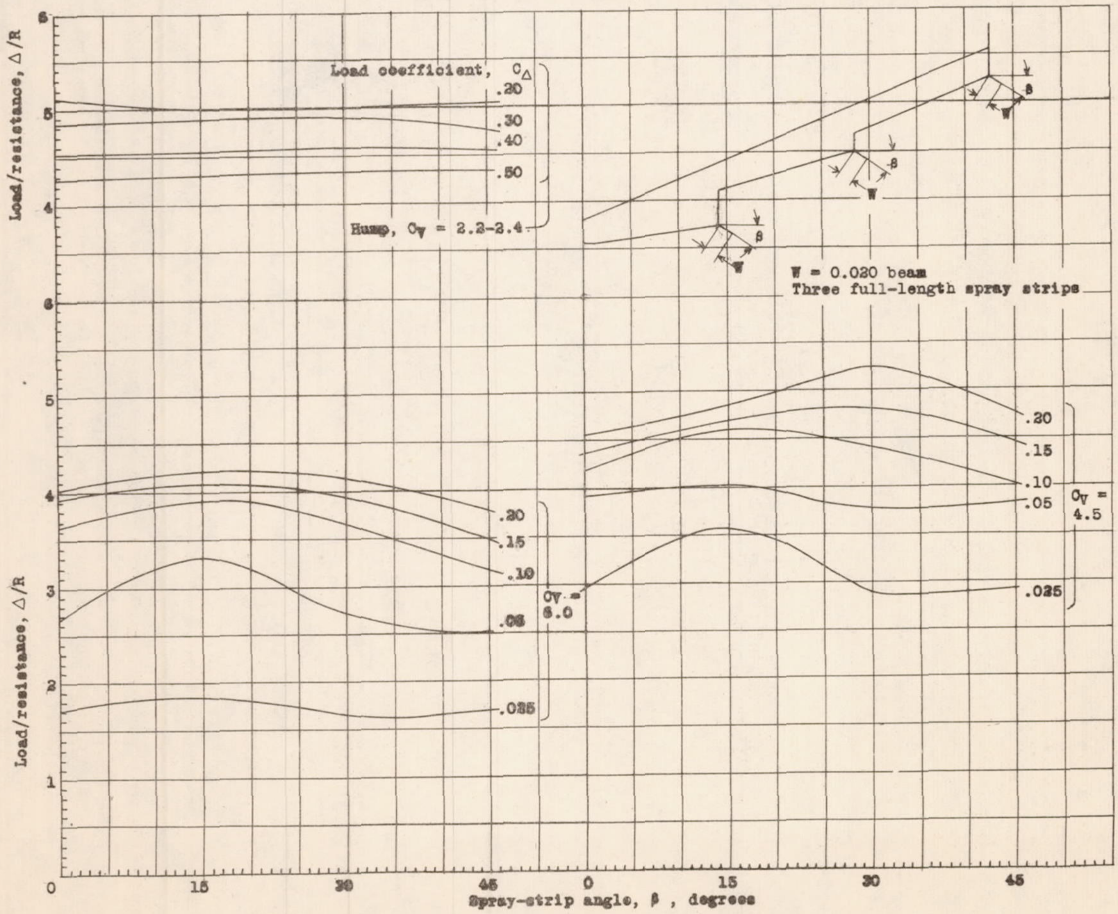


Figure 95.-Comparison of Δ/R for various angles of spray strip.
Model 11-E series.

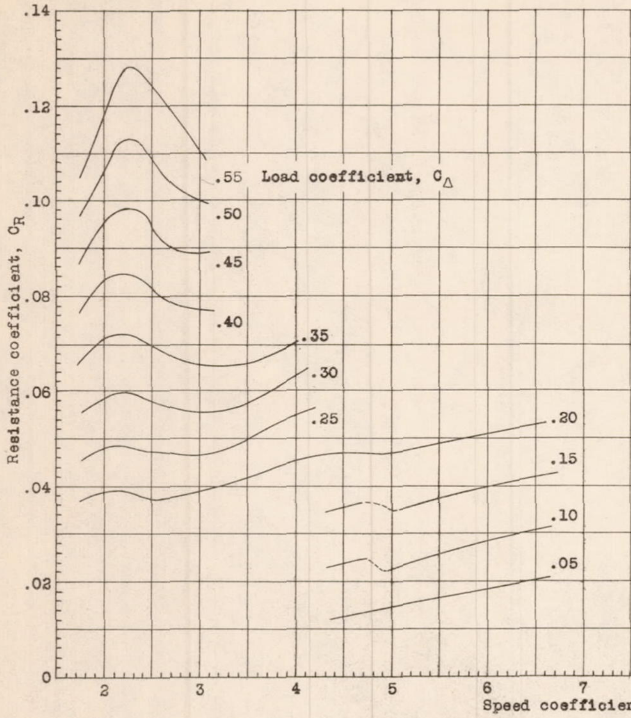


Figure 96.- Variation of C_R with C_V at best trim. Model 11-E-5.

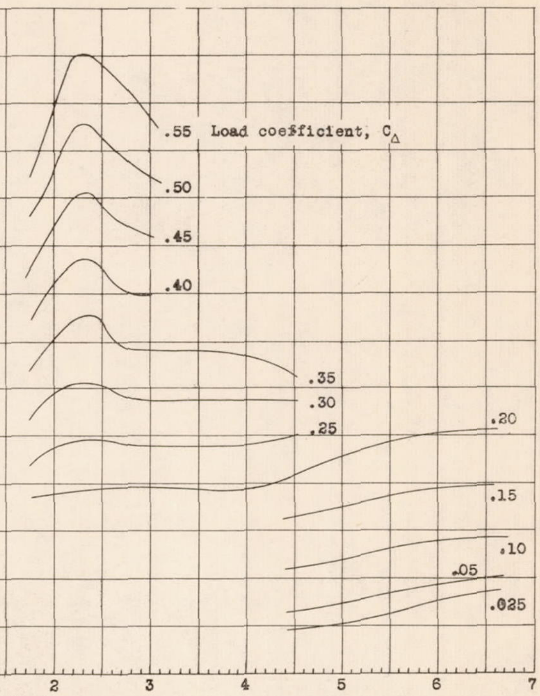


Figure 97.- Variation of C_R with C_V at best trim. Model 11-E-6.

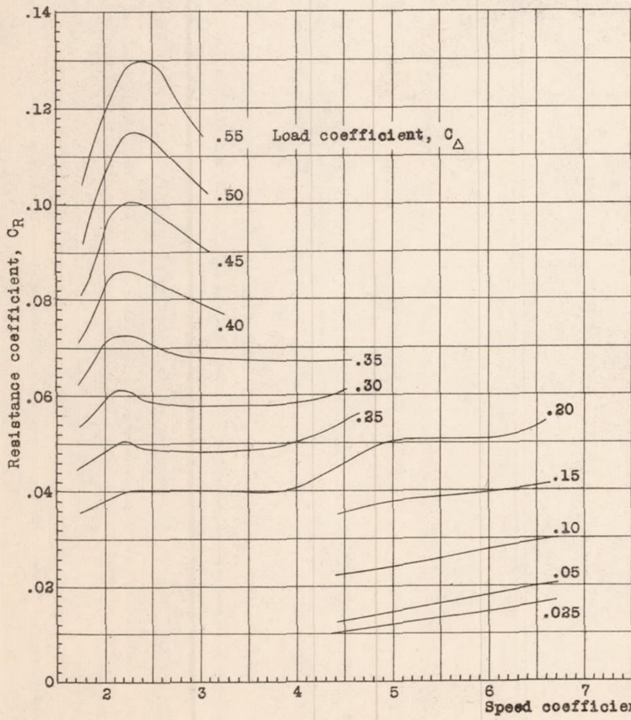


Figure 98.- Variation of C_R with C_V at best trim. Model 11-E-7.

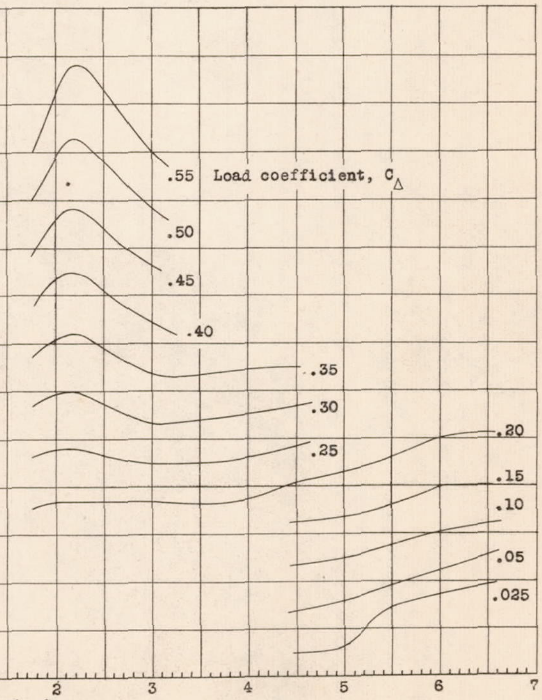
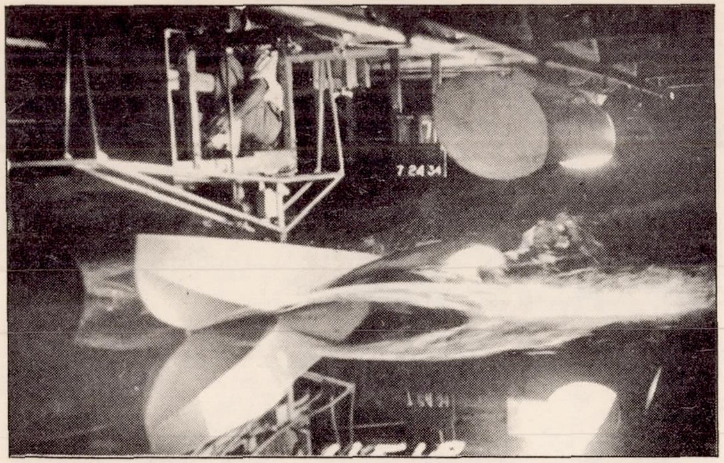


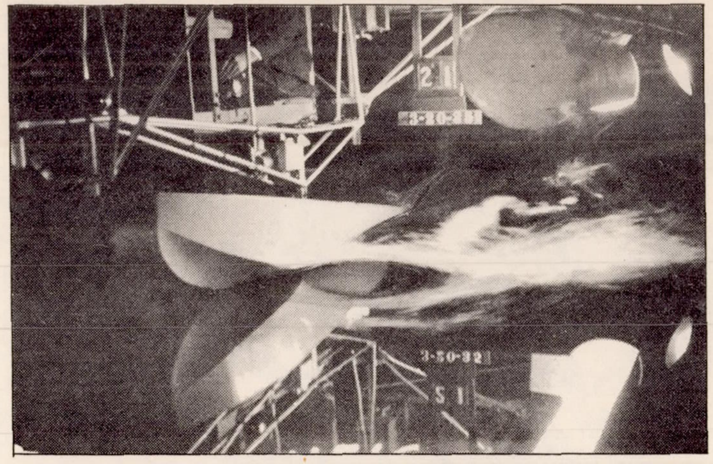
Figure 99.- Variation of C_R with C_V at best trim, Model 11-F-1.

Model 11-C
Parent model. No spray strips



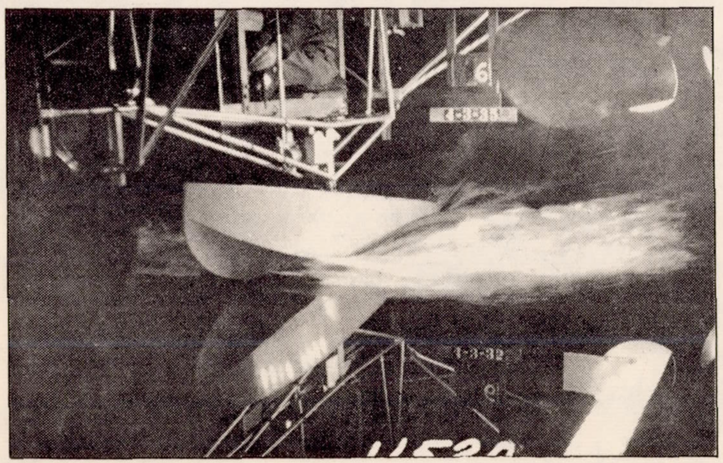
(a) Load, 100 lb., speed, 15.0 f.p.s., $\tau = 9^{\circ}$

Model 11-E
Two longitudinal steps, varying dead rise. No spray strips



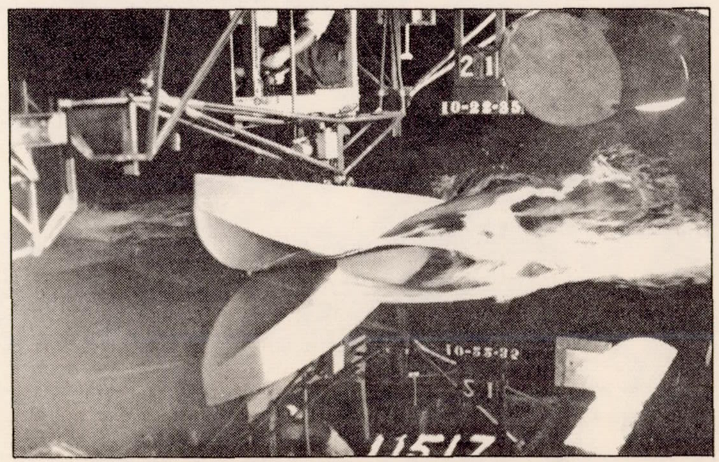
(b) Load, 100 lb., speed, 15.5 f.p.s., $\tau = 9^{\circ}$

Model 11-E-4
11-E with three full-length spray strips 0.020b wide set at 0°



(c) Load, 100 lb., speed, 14.9 f.p.s., $\tau = 9^{\circ}$

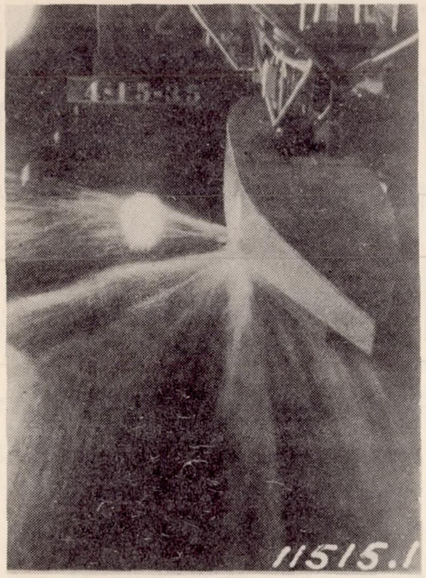
Model 11-M
11-E with inboard step filled in. No spray strips.



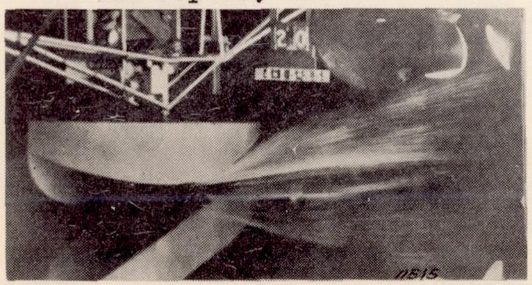
(d) Load, 100 lb., speed, 15.4 f.p.s., $\tau = 9^{\circ}$

Figure 100.- Photographs of bow wave of various models.

Model 11-F
Two longitudinal steps,
constant dead rise.

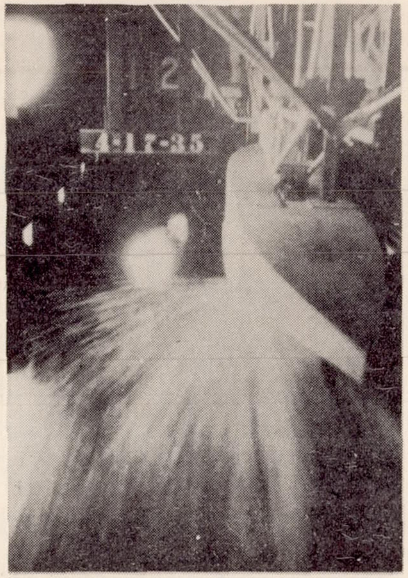


(a) Stern, load 40 lb., speed 36.0 f.p.s., $\tau = 5^{\circ}$

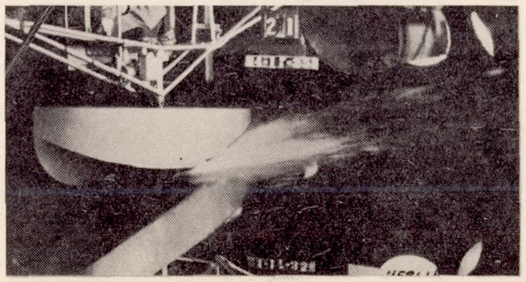


(b) Bow, load 40 lb., speed 36.0 f.p.s., $\tau = 5^{\circ}$

Model 11-F-1
11-F with spray strips
set at 30°



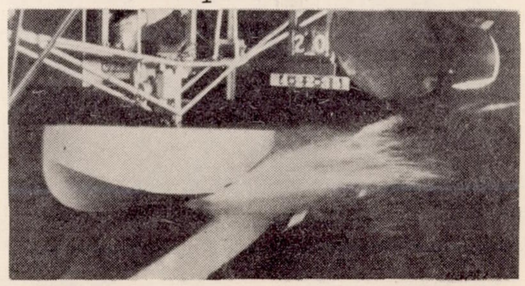
(c) Stern, load 40 lb., speed 34.6 f.p.s., $\tau = 5^{\circ}$



(d) Bow, load 40 lb., speed 34.6 f.p.s., $\tau = 5^{\circ}$

Model 11-F-3
11-F-1 with inboard strip
shortened to 0.61 b and outboard
strip shortened to 0.90 b.

(e) Stern, load 40 lb., speed 34.5 f.p.s.. $\tau = 5^{\circ}$



(f) Bow, load 40 lb., speed 34.5 f.p.s., $\tau = 5^{\circ}$

Figure 101.- Photographs showing effect of spray strips on height of spray.